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INCINERATOR GUIDELINES - 1969

Jack DeMarco, et al

Bureau of Solid Waste Management
Rockville, Maryland

1969

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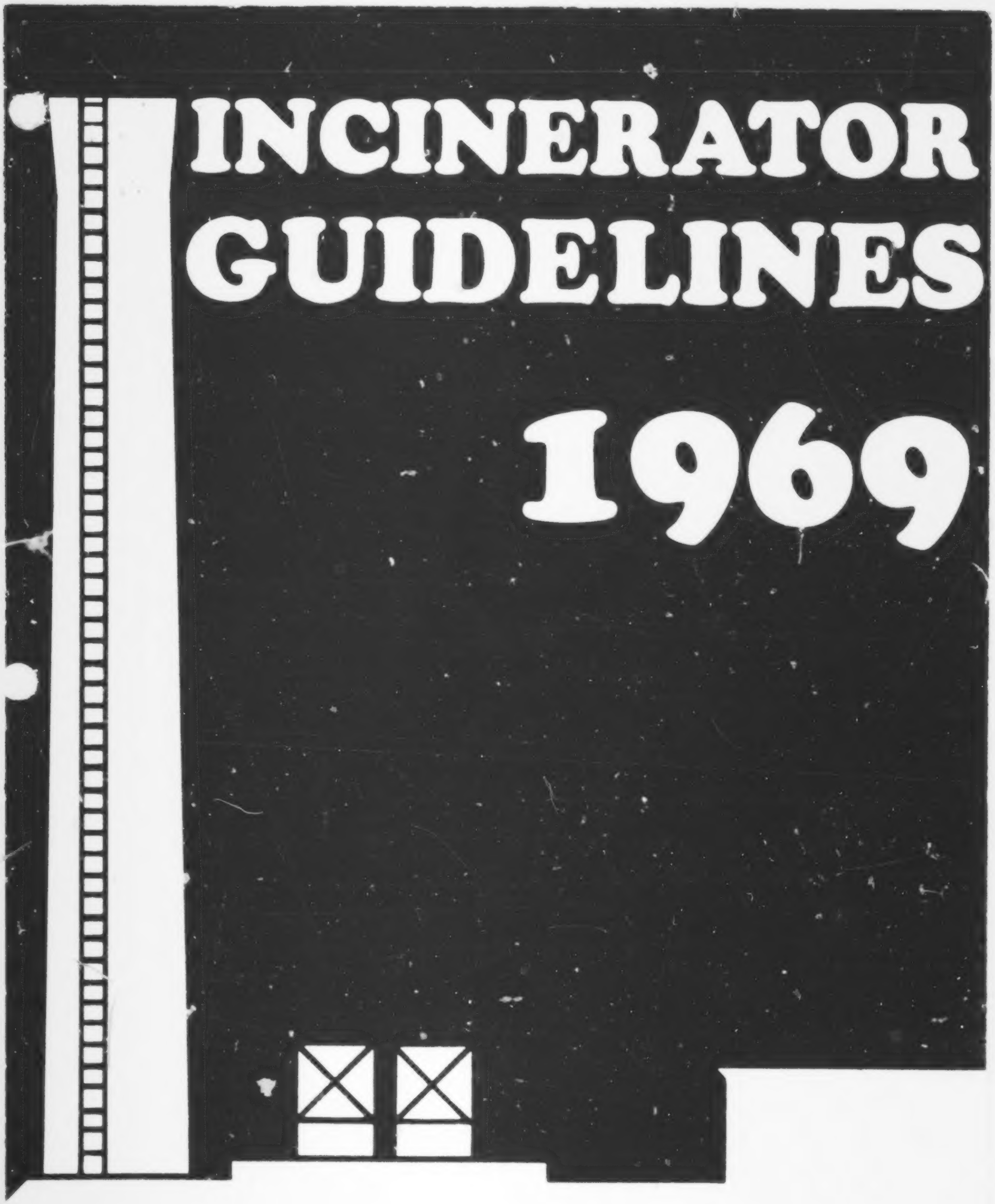

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INCINERATOR GUIDELINES — 1969

Jack DeMarco, Daniel J. Keller, Jerold Leckman, and James L. Newton

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FOREWORD

INCINERATION is a major method of solid waste processing in the United States today. Over the past several decades incinerator technology has been developed largely independently by industry, large institutions, and municipal and county governments. Independent development led to nonstandardized incinerator design and operation, and the diversity of regulations, design, and management practices failed to accomplish the major purpose of incineration: Maximum volume and weight reduction of solid wastes without environmental pollution.

The creation of the following Guidelines was conceived as a method of describing the best in incinerator technology in order to further its development. The publication is the result of a two-year effort. The work included many meetings and numerous drafts to synthesize published materials and information newly-written by both the staff and the panel members. The diversity of the incinerator design and operating practices, mentioned above, resulted in very divergent views that had to be brought toward concensus wherever possible. The final views expressed in the Guidelines are the responsibility of the Bureau of Solid Waste Management and the authors, who worked hard to state as fairly as possible the results of the long study. In the absence of firm technical data, this publication *(SW–13ts)* describes desirable performance characteristics for present-day incinerators, the process of incineration, and the "state of the art." The title represents this combined approach. The Bureau intends to review and revise the Guidelines at appropriate intervals to reflect the latest incinerator technology.

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Other staff members of the Bureau of Solid Waste Management actively contributing to this document included M. DeVon Bogue, Richard W. Eldredge, Charles W. Reid, Jr., and John B. Wheeler.

The Guidelines were reviewed by the American Society of Mechanical Engineers, the American Society of Civil Engineers, the American Public Works Association, the American Public Health Association, the Consulting Engineers Association, the Incinerator Institute of America, the National Solid Wastes Management Association, the U.S. Department of Health, Education, and Welfare's National Air Pollution Control Administration, the Bureau of Mines and Federal Water Pollution Control Administration of the U.S. Department of the Interior, and those State agencies with planning grants from the Bureau of Solid Waste Management. The Bureau is grateful for the time and effort contributed by panel members and these groups to the development of the Guidelines.

We hope that planners, designers, operators, and government officials will apply these guidelines to overcome poor performance of existing incinerators and that they will recognize the need for effective pollution control equipment. This publication should also create an awareness of the need for new incinerators of improved design and performance.

—RICHARD D. VAUGHAN, *Director*
Bureau of Solid Waste Management

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CHAPTER 1

INCINERATION: A VOLUME REDUCTION PROCESS

Incineration is a controlled combustion process for burning solid, liquid, or gaseous combustible wastes to gases and to a residue containing little or no combustible material. In this regard, incineration is a disposal process because incinerated materials are converted to water and gases that are released to the atmosphere. The end products of municipal incineration, however, must be disposed of. These end products include the particulate matter carried by the gas stream, incinerator residue, siftings, and process water. Incinerator residue consists of noncombustible materials such as metal and glass as well as combustible materials not completely consumed in the burning process.

The advantages of incineration are numerous, especially where land within economic haul distance is unavailable for disposal of solid waste by the sanitary landfill method. A well-designed and carefully operated incinerator may be centrally located and has been found acceptable in industrial areas so that haul time and distance can be shortened. The solid waste is reduced in weight and volume, and the residue produced can be nuisance-free and satisfactorily used as fill material. In a properly designed incinerator, the operation can be adjusted to handle solid waste of varying quantity and character.

An incinerator requires a large capital investment, and operating costs are higher than for sanitary landfill. Skilled labor is required to operate, maintain, and repair the facility. Thus capital and operational costs must be compared with the costs of alternate disposal methods, and full consideration must be given to the effects of the methods on the community and its neighbors.

The volume of municipal solid waste in the storage pit can be reduced 80 to 90 percent by incineration. In the process, usually 98 to 99 percent, by weight, of the combustible materials can be converted to carbon dioxide and water vapor. Total weight reduction is commonly 75 to 80 percent based on the weight of the as-charged solid waste, including moisture, reduced to a dry residue. Compaction of residue results in further volume reduction, so that solid waste processed in an incinerator and then compacted in a fill may occupy only 4 to 10 percent of its volume in the storage pit. A salvage operation can further reduce residue volume.

Oversized or bulky burnable wastes (logs, tree stumps, mattresses, large furniture, tires, large signs, demolition lumber, etc.) usually are not processed in a municipal incinerator since they are either too large to charge, burn too slowly, or contain frame steel of dimension and shape that could foul grate operation or the residue removal systems. A few incinerators include grinding or shredding equipment for reducing incinerable bulky items to sizes suitable for charging. In recent years, special incinerators have been designed and constructed to handle portions of bulky, combustible solid wastes without pretreatment.[1-3] Unless these materials can be incinerated, their bulk and abundance will add greatly to the amount of land necessary for final disposal. Other discarded large items, such as washing machines, refrigerators, water heater tanks, stoves, and large auto parts, cannot be handled by incineration, and they, too, add considerable volume to a fill.

The potential of incineration as a space conserving mechanism can be demonstrated by the following comparison: the volume requirements for final land disposal of an incinerator residue, with the volume requirements for a sanitary landfill system receiving unburned solid wastes.[4] Consider two identical samples of solid waste. Both are free of bulky solid waste. Assume that each sample is 2,000 lb and 13.3 cu yd (this is a bulk density of 5 to 6 lb per cu ft or roughly 150 lb per cu yd) and is typical of solid waste at the generating source.

System 1: Incineration. Based on the 75 to 80 percent weight reduction mentioned above, the residue produced from the incinerated waste could be estimated at about 523 lb. Studies have shown that incinerator residue may have a landfill compacted density of 2,700 lb per cu yd.[4] The 523-lb residue will thus occupy about 0.194 cu yd. The residue can be calculated as 0.194(100)/13.3 or 1.45 percent of the original volume.

System 2: Sanitary Landfill. The 2,000-lb sample occupies 13.3 cu yd. Compaction reduces the original volume of 13.3 cu yd to 2.2 cu yd. The reduction can be calculated as 2.22(100)/13.3 or 16.6 percent of the original volume.

The ratio of the remaining volumes of solid waste in the two systems is 1.45 percent to 16.6 percent, or a ratio of about 11 to 1. The favorable volume reduction by incineration is quite obvious for solid waste that does not contain bulky items.

For practical purposes, however, we must consider the disposal of bulky items and materials that ordinarily are not processed through conventional incinerators. Such materials make up about 20 percent, by volume, of community solid waste at the collection point and under good compaction in a landfill, can be reduced to approximately half their volume as collected. The volume conservation advantage of the incineration system over the landfill system is that of 23.3 percent to 11.16 percent, or 2.1 to 1 (Table 1).

TABLE 1

COMPARISON OF THEORETICAL INCINERATION AND SANITARY LANDFILL VOLUME REDUCTION RELATIONSHIPS

	Original volume units		Reduction factor		Final volume units
			Incineration		
Incinerable waste	0.8	×	0.0145	=	0.0116
Bulky and non-incinerable waste*	0.2	×	0.5	=	0.1
				Total	0.1116
			Sanitary Landfill		
Incinerable waste	0.8	×	0.166	=	0.133
Bulky and non-incinerable waste	0.2	×	0.5	=	0.1
				Total	0.233

*Nonincinerable wastes are defined in this study as those materials that ordinarily are not processed through conventional incinerators.

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CHAPTER II

BASIC DATA FOR DESIGN

Accurate basic data are needed to design successfully. These data include determination of present and future population to be served and the quantity, composition, and characteristics of the waste to be incinerated. Air, land, and water pollution control regulations and other constraints must be considered.

Few communities have sufficient information for designing an incinerator. Local studies are usually needed, therefore, to gather the data required for the community or region that will be served by the incinerator. Population projections and densities and the number, type, size and location of industries and commercial establishments are usually available from planning agencies, the Chamber of Commerce, or other community organizations. Useful records on the quantity and characteristics of solid waste being generated may be available from the municipal agency responsible for solid waste control. Local stipulations as to what wastes will be accepted for incineration, whether householders must separate their solid wastes, and the hours of incinerator operation must be considered by the designer. Some of the basic factors that influence design are discussed in this chapter.

Regulations

Incinerator design must meet regulations intended to preserve the quality of the environment and the health and safety of the operators. Local requirements include air and water quality standards, zoning, building and electrical code stipulations, and occupational health, safety, and sanitary regulations.

A designer must consider existing local, State, and Federal regulations and the regulations of neighboring communities. He should also recognize that more stringent regulations on air and water pollution can reasonably be expected in the future, and the design should be capable of meeting these higher future standards. To serve as a guide where no local regulations exist, this publication includes Executive Order 11282, May 26, 1966, "Control of Air Pollution Originating from Federal Installations" and standards by the Secretary of Health, Education, and Welfare implementing the objectives prescribed by the Order (Appendix B).

Population

Determining the present and future population to be served has several important purposes. An appraisal of population density aids in locating the incinerator at the most economic site. Another important use of population data is to estimate the quantity of wastes to be incinerated and, therefore, the incinerator capacity required for the designated area.

The population estimates should include the transient, commuter, and permanent domestic population at the time the survey is made, when the plant is to be opened, and over the projected life of the incinerator (usually 20 to

40 yr). In determining the future population to be served by the facility, the designer should consider the possible inclusion of adjoining developed areas within the metropolitan complex and the possible servicing of new areas as they develop.

Standard techniques are available for estimating current population. Some correlate the historical census records with an historical record of population indicators, such as number of water meters, water consumption, or other utility or commercial consumption. Other methods relate community growth to historical growth of nearby industries or other communities. Updated population projections often can be obtained from local, district, county, or State planning departments and from local utility companies.

Quantities of Solid Waste

The quantity of a community's solid waste will vary markedly with the climate, season, character of the community, the extent and type of commercial, industrial, institutional, and residential developments as well as the extent of usage of on-site incinerators and food waste grinders.

Per Capita Quantities. The continuing increase in the quantity of solid waste produced in the United States is attributed not only to increased population, but also to increase in per capita generation. The wide spread in the ranges of solid waste collected (Table 2) points out the need for local studies.

TABLE 2

PER CAPITA SOLID WASTE COLLECTED

Type	Quantity (lbs/capita–calendar day)
Residential (domestic)	1.5-5.0
Commercial (stores, restaurants, businesses, etc.)	1.0–3.0
Incinerable bulky solid wastes (furniture, fixtures, brush demolition, and construction wastes)	0.3–2.5

Weekly and Seasonal Variations. Seasonal fluctuations occur in the amount of solid waste generated and collected within the community and must be considered. This can be done by plotting weekly waste quantities averaged over 4-wk periods.[1] The fluctuations in waste quantities occur in yearly cycles, the maximum quantity almost always peaking during the warmer months. Because of many influences, the magnitude of fluctuations is significantly different from one community to another. Factors that influence variation are climate, weather, geography, tourism, holidays, consumption habits, collection procedures, and community size. Four-wk averages in waste generation within a community commonly range from ± 10 percent of the average weekly waste quantity; weekly variation in any year seldom exceeds 25 percent of the average weekly quantity for that year.[1]

Sizing. Because of large daily fluctuations in solid waste quantities, an incinerator should be sized on the basis of weekly quantities of solid waste to be incinerated. The storage pit should be designed to handle daily peaks in quantity.

One incinerator sizing method is based on the average weekly delivery for the highest 4-wk period projected for the design year. Another method of sizing is based on the use of a standard frequency diagram using weekly solid waste quantities and a time period of a year (Figure 1). With the use of a plot of this type, the incinerator size is based on the weekly solid waste quantity that will be exceeded a given percent of the time during a year. If the design was to be based on a weekly quantity that was exceeded 5 percent of the time, a weekly solid waste quantity corresponding to 95 percent would be selected from the frequency diagram.

In sizing an incinerator, the fact should also be considered that it will not operate continuously over the planned period. Past experience indicates that incinerators require about 15 percent downtime for repairs and maintenance.

Characteristics of Solid Waste

The design of the incinerator system, including furnace chamber, grates, feed mechanisms, and other parts, will vary because of differing waste characteristics and amounts. A plant to handle only household waste will differ from one that handles food waste from stores and restaurants or from one that handles only dry, high-heat-value industrial waste. The significant variations in composition that will actually occur in a particular community must be determined.

Not only has the per capita quantity of solid waste generated across the United States been increasing yearly, but the chemical and physical properties have been changing as well. The moisture content has been decreasing with diminishing household garbage, and the ash content has been decreasing as less coal is used for heating. Moreover, combustible content and heat value have been increasing, principally because of the ever larger use of paper and plastics. The net result has been to increase heat value of the "as delivered" solid waste to such an extent that greater furnace volumes and more combustion air are required to maintain the rated burning capacity of an incinerator.

Composition of Residential Solid Waste. Analysis of a composite of residential solid waste shows a range of percentages for material types (Table 3). As collected at the source in receptacles or piles, residential solid waste generally weighs between 100 and 300 lb per cu yd and averages 150 lb per cu yd. In the collection truck, solid waste is commonly compressed from 350 to 700 lb per cu yd. In the incinerator pit, the weight of the waste generally ranges from 300 to 550 lb per cu yd.

Bulky Solid Waste. Unless special provisions are made, combustible bulky items such as furniture, fixtures, and waste lumber present an operational problem when delivered to an incinerator. As already noted, exclusive of junked automobiles and

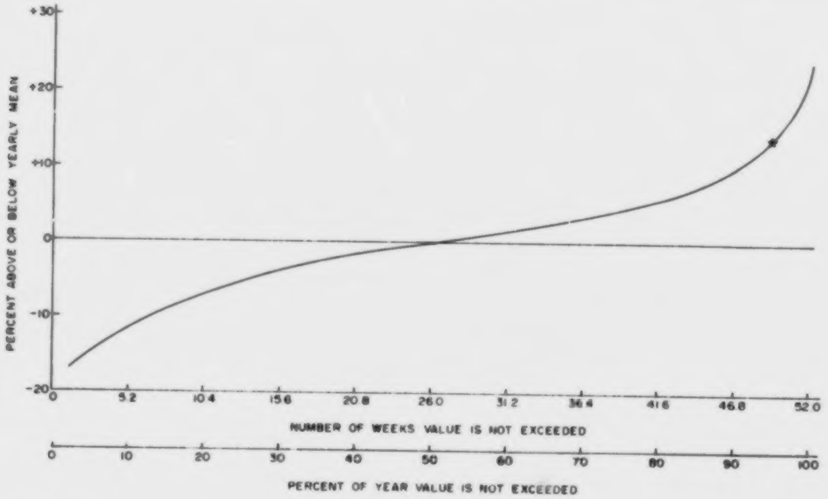

Figure 1. Frequency diagram of cumulative weekly solid waste quantities delivered for disposal during a year. At the asterisk, 95 percent of the year (49 of 52 wk) the quantity of solid waste did not exceed 15 percent above the average yearly mean.

TABLE 3

RANGE IN COMPOSITION OF RESIDENTIAL SOLID WASTES IN 21 U.S. CITIES

Component	Percent composition by net weight		
	Low	High	Average
Food waste	0.8	36.0	18.2
Garden waste	0.3	33.3	7.9
Paper products	13.0	62.0	43.8
Metals	6.6	14.5	9.1
Glass and Ceramics	3.7	23.2	9.0
Plastics, rubber, and leather	1.6	5.8	3.0
Textiles	1.4	7.8	2.7
Wood	0.4	7.5	2.5
Rock, dirt, ash, etc.	0.2	12.5	3.7

*Unpublished data, Division of Technical Operations, Bureau of Solid Waste Management. Values were determined from data taken at 21 cities in continental United States between 1966 and 1969.

demolition waste, nonincinerable waste amounts to about 20 percent by volume of total community solid waste. Of this, about 50 percent is combustible material. Separate collection service has frequently been employed to reduce the number of such items delivered to the incinerator. Recently the trend has been to design incinerators capable of processing almost everything.

Shredders and grinders are now being used at some incinerators, and specialized incinerators have been used for bulky waste alone.[2,3] The operational problems encountered in handling bulky solid waste are discussed in Chapter XIV.

Other Characteristics. The heat values and the proximate and ultimate analyses of the solid waste as delivered to the incinerator (Table 4) are used in calculating heat release rates, combustion and excess air volume, grate area, draft, and other factors. Proximate analysis is the determination of moisture, volatile matter, fixed carbon, and ash expressed as percentages of total weight of the sample. Ultimate analysis is the determination of moisture content, noncombustibles, and the carbon, hydrogen, oxygen, nitrogen, and sulfur content.

Data on the proximate analysis, ultimate analysis, and heat values of individual waste components such as newspaper, cardboard, grass, meat scraps, fruit peelings, etc., have been published.[4] These data can be used to estimate proximate analysis, ultimate analysis, and heat value once the composition (% by weight) of a waste is determined.

The methodology for obtaining a representative sample of solid waste and its analysis has been described by the American Public Works Association.[5] Oxygen bomb calorimetry for determining the amount of heat liberated from solid materials and from liquids has been described.[6]

The ultimate analysis provides a means for a rational approach to furnace design and is required for a complete materials balance of incoming and outgoing material. Significant variations in these values can occur with seasonal and climatic change. Variation in moisture is particularly critical; the maximum, mean, and minimum moisture value should, therefore, be determined to provide a range for best, average, and worst conditions. If these varying conditions are

TABLE 4

PHYSICAL AND CHEMICAL CHARACTERISTICS OF INCINERATOR SOLID WASTE*

Constituents	Percent by weight (as received)
Proximate analysis	
Moisture	15-35
Volatile matter	50-65
Fixed carbon	3- 9
Noncombustibles	15-25
Ultimate analysis	
Moisture	15-35
Carbon	15-30
Oxygen	12-24
Hydrogen	2- 5
Nitrogen	0.2-1.0
Sulfur	0.02-0.1
Noncombustibles	15-25
Higher heating value	*Btu per lb (as received)* 3,000-6,000

*Principally residential-commercial waste excluding bulky waste.

recognized, the incinerator can be designed to operate under them.

Heat value is one important characteristic of solid waste needed for incinerator design. The term "heat value" can be used in several different ways. One way, the "higher heat" value or "gross heat" value, is the total amount of heat released per unit weight of material that is burned. The higher heat value is determined by oxygen bomb calorimeter measurement, although it can be estimated from chemical composition of the sample material if known. Another way of expressing heat value is called "net" or "low" heat value. To determine this value, the latent heat of vaporization of all moisture resulting from the combustion process is subtracted from the high heat value.

As mentioned above, the long-term trend in the United States has been for the combustible fraction (principally dry paper and plastics) of municipal solid waste to increase and for the moisture content to decrease (mainly because of the decrease in wet food waste). Hence, the heat value of waste as received at the incinerator is rising. At present, incinerator designers are using gross heat values ranging from 3,000 to 6,000 Btu per lb based on waste as received. The present trend indicates that heat values of incinerator solid waste will increase by 500 Btu per lb by 1980.

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CHAPTER III

INCINERATOR COSTS

Incinerator costs are divided between those related to ownership and those related to operation. Ownership costs derive from the capital costs of financing the incinerator construction and are usually paid off through depreciation and interest charges. Operating costs include the direct and indirect costs of operating and maintaining the plants. This chapter presents costs for existing municipal incinerators and outlines the major factors that influence costs.

Knowledge of capital costs of existing incinerators is of interest as the basis for understanding, at the planning stage, how much money is involved in constructing an incinerator. It is also prerequisite to determining total costs. These total costs of ownership and operation are necessary to compare different incinerators and to evaluate incineration with other methods of solid waste disposal. The data included in this chapter present national averages of these costs and can be used for general comparisons or planning purposes.

Although costs are necessary in comparing the operation of different incinerators, the primary use of cost data is for effective management. An example of an accounting system that may aid in obtaining data is included in Appendix A.

Capital Costs

The capital costs of 170 municipal incinerators were obtained from the U.S. Public Health Service National Survey of Community Solid Waste Practices data. The capital costs are reported as the 1966 estimated replacement costs and include the costs of buildings, facilities, and engineering, but not land.

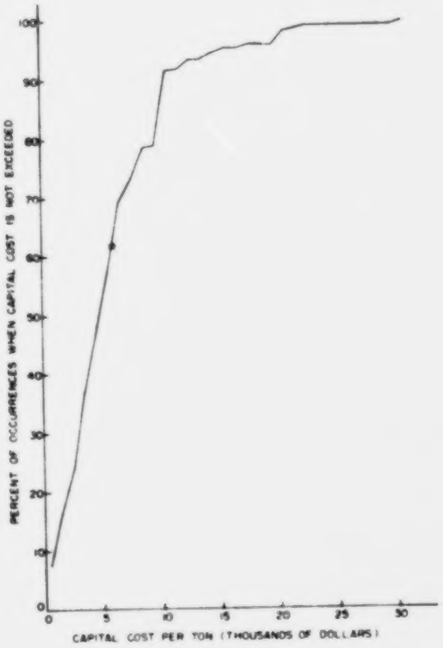

Figure 2. Cumulative frequency diagram of capital costs for 170 municipal incinerators in $1,000 increments. At the asterisk, 62 percent of the incinerators have capital costs below $6,150 per ton (24-hr design capacity).

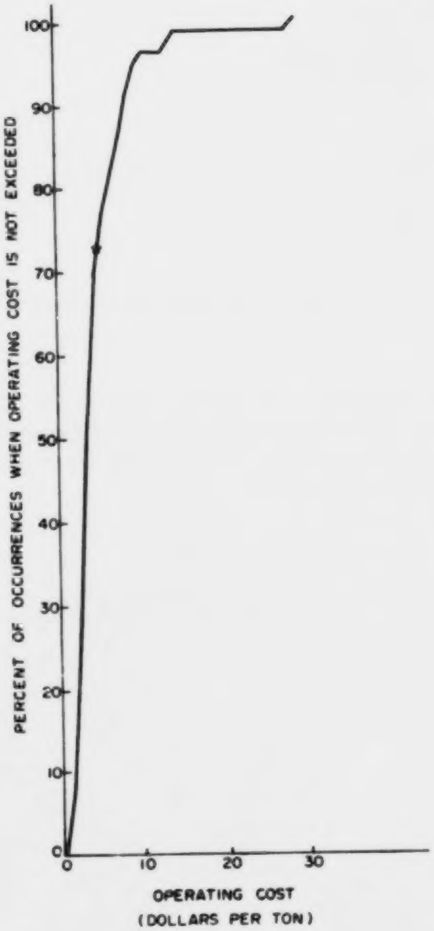

Figure 3. Cumulative frequency diagram of operating costs for 78 municipal incinerators in dollar-per-ton increments. At the asterisk, 73 percent of the incinerators have operating costs below $5.00 per ton solid waste received.

These data indicate an average capital cost of municipal incinerators at about $6,150 per ton (24-hr design capacity). (Example: capital cost of $600,000 ÷ 100-ton-per-day capacity = $6,000 per ton.) Sixty-two percent of the incinerators studied cost less than $6,150 per ton (Figure 2). Fifteen plants reported capital costs above $11,000 per ton. The highest capital cost, reported by only one plant, was $30,000 per ton.

Some of the major equipment cost items included in capital costs are scales, cranes, furnaces, blowers, air pollution control devices, process waste treatment and recycling equipment, residue removal systems, instrumentation, waste heat recovery equipment, steam distribution equipment, and flue and duct equipment. Major construction items on the structure include building, ramps, tipping area, storage pit, refuse hoppers, offices, employee facilities, piping, and chimney. Miscellaneous items under capital cost include site preparation, excavation, foundation preparation, roadway and sidewalks, landscaping and seeding, furniture and fixtures, machine shop equipment, and tools.

Fly-ash control equipment has, in the past, amounted to about 3 percent of the total capital cost of municipal incinerators.[1] To achieve particulate removal as required by the new and more stringent air pollution control regulations, the cost of control equipment will now range from 8 to 10 percent of the total capital cost.

Capital cost components and their relative importance may be grouped as follows: furnaces and appurtenences (55% to 65%); building (20% to 30%); air pollution control equipment (8% to 10%); miscellaneous (7% to 13%).

Operating and Owning Costs

The 1968 National Survey data also provided information on operating costs of municipal incinerators. Since the calculation of the costs per ton of solid waste processed is dependent on weighing the material, this discussion is limited to the facilities (78) that actually weighed their incoming solid waste.

The Survey data on operating costs gave an average cost of operating municipal incinerators of $5.00 per ton of refuse processed. Seventy-three percent of the incinerators studied had operating costs below $5.00 per ton (Figure 3). Four of the 78 plants reported operating costs above $10 per ton.

The wide variation in operating costs resulted partly from differences in the amount and types of pollution control equipment, labor rates, cost of utilities, residue disposal costs, and amounts of automation. Reported operating costs are also influenced by the fact that some cost items are not included when calculating the total operating cost. For example, for many incinerators, the cost of utilities, administration, or employee fringe benefits are not included in operating costs.

Ownership costs include the financing costs associated with the depreciation and interest of the facility. The costs for depreciation and interest have been commonly given to be between $1.00 and $2.00 per ton. In practice the actual costs can vary significantly depending on factors such as utilization rate, estimated life, and interest rates. Total costs of ownership and operation can be stated either for a time period or for the quantity of wastes incinerated, for example, annual cost or cost per ton (Table 5).

TABLE 5

TYPICAL INCINERATOR COST CENTERS

Operating costs
Labor (operating and maintenance)
Salaries
Vacation and holiday pay
Sick and injury pay
Training
Fringe benefits
Pensions
Utilities
Water
Electricity
Gas or fuel oil
Miscellaneous charges
Materials and supplies
Contract work
Overhead
Management
Charges from other administrative departments
Ownership costs
Depreciation
Interest

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1. American Public Works Association. Municipal refuse disposal. 2d ed. Chicago, Public Administration Service, 1966. p. 145.

CHAPTER IV

SITE SELECTION, PLANT LAYOUT, AND BUILDING DESIGN

Proper location of the incinerator enhances acceptance by the public and results in economies in waste collection. A well-planned physical layout facilitates efficient and economic incinerator operation. Good design and selection of appropriate building materials promotes a pleasing appearance and minimizes housekeeping and maintenance.

Site Selection

Public Acceptance. Public acceptance is a most important consideration in selecting an incinerator site. A few suggestions for gaining public acceptance follow.

1. Choose a site where construction can conform with existing and planned neighborhood character. In general, industrial and commercial areas are more compatible with incinerators than residential areas. An incinerator plant is usually classed as heavy industry, and the evaluation of its location should reflect this. Too frequently the vacant land surrounding an incinerator is later developed for residential or other restricted use, which creates conflict. To avoid potential conflict, the undeveloped, surrounding land should be zoned for industrial use.

2. Avoid choosing a site that may conflict with other public buildings. The noise, lights, and 24-hr workday of normal incinerator operation preclude locating it near a hospital, and heavy truck traffic makes incinerator location near schools undesirable.

Centralized public works operations are desirable. Often an incinerator plant can be advantageously located near a sewage treatment plant so that technical services may be shared. There may be ecomomies in locating the incinerator near a garage where vehicle repair facilities and personnel can be shared.

3. Where conflict with neighborhood character is unavoidable the screening effects of a wall or planting can reduce adverse effects and gain public acceptance. Good architectural design is itself a major asset in overcoming potential neighborhood objection.

4. Institute an effective public relations program. Before full site and design decisions are made, proposals and plans should be presented through the press and for discussion at public meetings. This would serve to demonstrate management response to community desires and a capability for operating an acceptable facility. Presentation of alternatives along with rationale for incineration may be supported by graphic examples and site visits to successfully operating facilities.

Site Suitability. Factors important to design, but generally not of concern to the public, are foundation conditions, topography, availability of utilities, building restrictions, drainage, and meteorologic conditions.

Soil and rock formations determine the type of foundation required to support the heavy, concentrated load of an incinerator structure. Failure to accurately determine foundation conditions and design to them can result in expensive modifications during construction and, in certain cases, abandonment of the site with its partially completed structure. Groundwater conditions also affect design and cost.

Topography and meteorological conditions must be considered in the location and the design of the incinerator. A flat site is apt to require a ramp for access to the tipping floor, whereas a hillside site can provide access at various ground levels. Topography can also ease or hinder the dispersion of gases and particulates by the local atmosphere. This aspect of plant location is complex and requires the assistance of a meteorologist or air pollution control specialist, who can determine the best stack height for the dispersion of gases. Stack height determination requires consideration of topography and legal restrictions, such as those from Federal Aeronautics Agency regulations, local building regulations, and zoning.

Availability of public utilities may be a governing factor in site selection, since electricity, gas, water supply, sewage disposal, and process water disposal are essential to the incinerator process. Fuel such as gas or oil may be required at some installations as an auxiliary heat source for the furnaces or as building heat. Communication facilities must be available for fire and safety control and for coordinating operations.

As in the development of any industrial site, effective drainage of surface waters must be an integral part of design. The site should not be selected in an area subject to flooding unless the facility can be protected and access remains available during high water.

Traffic Consideration. The ideal location for an incinerator is at the center of the traffic pattern produced by the contributing collection vehicles. A major argument already made for incineration in comparison with land disposal was that incineration can reduce the time and cost of collection haul. This requires that the incinerator be centrally located. This is not always feasible for a variety of reasons. For example, future growth and its effects on the collection source must be considered.

A large plant may have literally hundreds of vehicles delivering solid waste in relatively short time intervals. Because of heavy traffic, the plant must have adequate access to preclude safety hazards in the streets of the area. Special access roads may have to be provided so that the trucks avoid heavily traveled highways. Special consideration also must be given to traffic impediments such as bridges with low weight limits, restrictive heights of overpasses, narrow pavements, and railroad grade crossings with high volume traffic. A location that avoids commuter traffic is also preferred. Thus, a plant located near the edge of the participating community but readily accessible by freeways or beltways may be better than one centrally located. The same traffic considerations apply to residue disposal. On-site disposal is often not possible; therefore, incinerator residue and nonburnables must be trucked to a landfill.

Plant Layout

An incinerator plant layout should promote ease, simplicity and economy of operation, and maintenance. There should be adequate room for all parts of the operation. The structure should harmonize with the surrounding neighborhood and should be so oriented that unsightly parts of the building and operation (such as receiving and storage) are not visible to the public. In certain climates, it is advantageous to orient the receiving area on the leeward side of the prevailing wind. The on-site road pattern should allow ready access to scales and receiving area and an easy exit; one-way traffic is most desirable; sharp turns and blind spots should be avoided; and a large parking apron should be provided outside the receiving area to avoid congestion during peak receiving hours.

Adequate drainage is necessary for surface waters. Incinerator operation requires periodic hosing of tipping floor, vehicle wash areas, parking aprons, and ramps. The paving should be sloped and contain adequately sized and strategically placed drains. This is particularly critical in cold climates where ice formation could interfere with operations.

Maintenance and storage of trucks may be inside the incinerator building or on the grounds, but these areas must be located where they will not hamper the operation of the incinerator.

Building Design

The incinerator should be aesthetically pleasing and should be constructed of durable, high-quality materials and fixtures to reduce maintenance. Materials requiring a minimum of painting or resurfacing, such as concrete, tile, and noncorrosive metals, should be used. Surfaces that require painting should have a dense, durable finish. Corners and bases can be coved to reduce accumulation of debris and allow easier cleaning. Where possible, piping and duct work should be enclosed.

Personnel Facilities. Adequate facilities for incinerator personnel are more a matter of convenience and may well represent the difference between a working situation that is conducive to efficiency and cleanliness as opposed to one that may create an indifferent and inefficient work crew. A clean locker room is needed, with adequate toilet, lavatory, and shower facilities. Lockers should have space for storing hard hats, rain and winter gear, and a full change of clothing. Sanitary facilities should be provided for women who may visit or be employed at the plant.

Lunchroom facilities should also be provided along with a sink and suitable outlets for coffee percolators. Drinking water should be available on every floor and within 200 ft of employee stations. The lunchroom, locker room, shower, and toilet areas should be well lighted and kept clean at all times to encourage habits of cleanliness by the workman. It is often desirable to provide washroom facilities convenient to collection personnel, weighmasters, and others.

Control Room. Many large incinerators are now being built with glassed-in control rooms so located that the incinerator superintendent or shift foreman can readily observe various operations. Because all areas of the plant or operating conditions within furnaces cannot be observed from one location, closed-circuit television is used in some instances. The importance of the glassed-in area (ventilated and air conditioned) is not merely to provide comfort to the superintendent and foreman, but to protect delicate recording instruments from dust and to minimize the noise level in an area where telephones are used. Written records are also better maintained in an isolated control room area. The control room should be suitably equipped with remote reading and recording instruments that provide supervising personnel with the information necessary to adjust the incinerator operation if it is not performing suitably.

Administrative Offices and Conference Room. In the larger incinerator plants, sometimes the superintendent, foremen, and clerical workers need an office to conduct necessary administrative activities. Attractive decor and air conditioning will improve morale and efficiency. Smaller incinerators may effectively combine the operating control room with space for administrative activities.

At larger plants, a conference room for staff briefings, safety discussions, and training purposes is a worthwhile investment.

Weighmaster's Office. The weighing activities may be conducted alongside the access road outside the incinerator plant or at the entrance to the turning and tipping area within the plant proper. In either instance, the weighmaster should have a facility with ample glassed area to observe the movement of weigh scale traffic. He should have ready means of communicating with the driver, handling credit cards, or making cash transactions.

Maintenance and Repair Facilities. Regardless of the size of the incinerator, storage space for electrical, mechanical, and refractory parts and an enclosed area where repair and subassembly may be performed must be provided. For very large plants, separately maintained storerooms for parts, electric shops, mechanical shops, and enclosed refractory storage facilities should be included. Where a large municipality has a number of incinerators, central maintenance and repair facilities for major activities may prove economical. There should be storage facilities for such items as lawn mowers, skip loaders, mechanical sweepers, refractories, pipes, insulation material, and the various chemicals required for insect and other pest control.

Laboratory. The incinerator must be so operated that the environment is not polluted. Federal, State, and local regulations are becoming more restrictive. Surveillance of the water quality of incinerator effluent is needed to ensure pollution control, and a small laboratory and testing equipment should be provided for this purpose. Municipalities with several incinerators should consider a centralized laboratory facility.

Interior Lighting. At many municipal incinerators the interior lighting is poor. Recommended lighting standards for various industrial operations are published by the illuminating Engineering Society,[1] and lighting standards exist for certain tasks similar to those performed at incinerators (Table 6).

TABLE 6

LIGHTING STANDARDS APPLICABLE AT INCINERATORS

Office and industrial tasks	Foot-candles on task
Loading and trucking	20
Corridors, elevators, stairways	20
Rough, easy assembly work	30
Reading high-contrast or well-printed material, tasks and areas not involving critical or prolonged seeing such as conferences, interviews, inactive files, and washroom	30
Medium bench and machine work, rough grinding, medium buffing and polishing, difficult inspection	100
Regular office work, reading good reproductions, reading or transcribing hand writing in hard pencil or poor paper, active filing, indexing references, mail sorting	100

Plant Exterior

Roadways, Sidewalks, and Parking Areas. In designing the roads providing ingress to an incinerator site, consideration must be given to peak loading periods and types of vehicles that may utilize the incinerator. Where possible, the roadway system should be built so that the traffic flows only in one direction, thus providing only one entrance and one exit. Arrangements must be made for obtaining truck tare weights without interfering with one-way traffic flow. This is possible even where scales are used, provided the trucks being serviced all have established tare weights. When transient traffic is being weighed, so that a "weighout" is necessary, a roadway may be provided within the site that will allow the trucks to return across the scale for the second weighing in the same direction as the normal flow of traffic. All roadways should be sufficiently wide to permit the passage of one vehicle past another in the event that a truck is stalled. Road grades should be suited to the traffic operating on the grades. In general, the grades for short-distance truck travel should not exceed 7 percent uphill and 10 percent downhill. Pavements should be hard surfaced, all weather, and designed for heavy loads. Curbing, posts, or guardrails should be used to confine traffic to roadways.

Incinerator plants should be provided with sufficient sidewalks to ensure that visitors and plant personnel will be able to walk safely about the premises without being endangered by vehicular traffic.

Parking areas are generally divided into two categories: (1) parking for administrative and operating personnel, visitors, and temporary parking for collection vehicles, (2) parking for overnight storage of collection vehicles and for equipment used at the incinerator site such as mobile sweepers. In areas with severe winters, parking facilities inside heated garage areas are desirable to permit proper maintenance, cleaning, and protection of the collection vehicles.

Landscaping. Perimeter planting around an incinerator site presents a pleasing appearance and reduces the noise of the truck traffic from within the property. For maximum benefit and to further enhance the appearance, trees and shrubbery can be placed outside the fencing. Provisions must be made in advance for adequate watering and for access so that periodic trimmings may be performed without unreasonable expense. Built-in sprinkling systems should be considered for lawn and shrub areas.

Fencing and Lighting. Where the incinerator plant is located in an area subject to vandalism, peripheral fencing is desirable with a minimum height of 6 ft with three strands of barbed wire on a 45° angle projection at the top. Such fences should be constructed of low-maintenance, rustproof metal. Gates should be similar in design and provided with sturdy locks. The substitution of peripheral plants for fencing is usually not desirable, since most hedges can be penetrated by intruders.

External lights placed on the incinerator building are adequate to light most incinerator sites. If the building lights should prove objectionable to the surrounding neighborhood, perimeter lights on stands directed towards the incinerator plant may be preferable. Light stands should also be provided along the on-site roadways used by collection and incinerator vehicles.

Traffic Control. Signs for the control of traffic should be simple and the lettering should be large. Where one-way control of traffic is desired, the entrances and exits should be clearly indicated. Proper design of roadways and directional markings on the pavements, such as arrows and centerline striping, will lessen the need for traffic signs. A stop sign or signal placed at the entrance to the scale is essential. At very large plants, electrically controlled signals operated by the weighmaster may be desirable to route traffic. Signs should be informative and clearly visible so that visitors to the plant, as well as routine users, will have no difficulty entering and leaving the plant.

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CHAPTER V

UTILITIES

For efficient operation, a municipal incinerator requires certain utility services, which include: (1) electricity for power and lighting; (2) potable water for plant personnel and suitable process water for spraying, heating, quenching, cooling, and fire fighting; (3) telephone service; (4) sewerage systems for handling process waste and sewage, and storm sewers for drainage; (5) fuel for heating, hot water, auxiliary heat for incineration, and possible laboratory use. Each of these utilities supplied to the incinerator site must be metered and distributed safely and efficiently to all points of usage at the site.

With increasing incinerator capacities and with increasing use of sophisticated equipment and devices, more utility services will be required. The cost of providing these utilities depends on the plant design and mode of operation and may reasonably be expected to range from $0.10 to $1.00 per ton of waste processed.

Electric Power

With few exceptions, utilization of incinerator waste heat to generate electric power is not practiced in the United States. The incinerator's electrical power is obtained from other sources.

Electric power requirements vary with the degree of mechanization and the use of equipment. Common examples of equipment requiring electricity are induced draft fans, forced-air fans, pumps, cranes, hoists, air pollution control devices, and grate-driving mechanisms. Allowance for future electrical needs should be included in planning and sizing the electrical distribution systems. For some facilities, electric power can cost as much as $0.75 per ton of waste incinerated.

The voltage for the lighting system is usually 110 volt, although higher voltage fluorescent and mercury-vapor lamps are becoming widely used. The latter types have higher first cost, but provide lower maintenance and operational cost. Most instrumentation operates on standard 110- to 120-volt power, but there are times when voltage regulators and transformers are used to maintain a constant voltage or a lower voltage to certain circuits.

To prevent damage to the structure and equipment from smoke and overheating due to power failure, an emergency standby power system is needed. Alternate safety measures include automatic, temperature-control devices such as a water cooling system, using city water or stored water, and emergency openings in the furnace to bypass air pollution control equipment.

Peak power demands frequently are considerably in excess of average power consumption and may require special provisions. The cranes and shredders could demand extra power and cause severe current fluctuations that result in power shortage and equipment failures. The electrical system should be designed to accommodate the power demand.

Water Requirements

The quality of the water required for incinerator operation will depend on its use. Sources may include: city water, on- or off-site wells, rivers, lakes, and wastewater treatment plant effluents. The total amount of water required may vary from 350 to 2,000 gal per ton of waste incinerated depending on design and operation.[1,2] Cost for this portion of the utility service is from $0.07 to $0.40 per ton of waste incinerated, based on a water rate of $0.20 per 1,000 gal. Incinerator operation requires a dependable water supply. An elevated water supply serves this purpose and can be used for fire fighting. When waste heat is used to produce steam or hot water, the boiler feedwater and makeup water will require extensive pretreatment. Water for air pollution control equipment, for gas cooling, and for dust control sprays need not be potable, but should be free from suspended materials. Water used in the incineration processes will increase in temperature, change in chemical characteristics, and will acquire solids. Treatment may be required before these waters are discharged.

The costs of water recycling and reuse should be investigated. In reuse and recycling, treatment should be effective in preventing clogging, erosion, and corrosion of equipment.

Sewers

Preferably, the incinerator should be located in an area served by sanitary sewers. Untreated waste process water should be disposed of through the sanitary sewer if the system is capable of handling it. Storm sewers should be used only for discharge of surface waters.

Communications

External telephone communications are normally provided by a trunk line from the switchboard serving the municipality. Communications within the plant are best provided by an intercom system. Public address systems, bells, and other devices may also be effective. Soundproof booths with a visible signal system have been used in areas with continuous high-noise levels.

Extensive, closed-circuit television monitoring is being utilized in the power generation industry for supervision and for observing the combustion process. Although attempts have been made to monitor large incinerators, systems for this purpose are still in the development stage.

Fuels

Fuel may be required for plant processes, including building and water heating, and for auxiliary fuel. The choice of fuel for these purposes will depend on availability and cost. The need is determined by local conditions and incinerator design.

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CHAPTER VI

WEIGHING

An incinerator scale weighs incoming solid waste and outgoing residue, including fly ash and siftings. It may also be used to weigh salvaged materials. Accurate and meaningful weight records can be used to improve operation, to assist management control, to facilitate planning, and to provide an equitable means for assessing fees. Weights are needed for cost accounting, rating the effective capacity of the incinerator, testing air pollution control devices, and making a materials balance for the facility.

A management system making use of weights can serve to regulate and control solid waste collection and disposal. Good collection scheduling and routing may depend on such a system. Distribution of waste deliveries among available plants requires prompt access to weights of incoming material. Cost control to increase efficiency and eliminate excessive expenditures of time and effort is dependent on weight units.

Observation of the trends in quantity, sources, and types of solid waste collected will assist in planning for future disposal needs. Weight records of residue assist in determining the remaining life of residue disposal sites, and thus assist effective planning as well as provide a means of calculating combustion efficiency. If a community wishes to charge other communities, private haulers, or commercial haulers for using the incinerator, the weight measurements will provide a practical, equitable means for assessing fees.

Scale Description

Scale Types. A small incinerator (50 to 100 tons per day) may satisfactorily use a wood platform, manually operated, mechanical scale and keep handwritten records. At the other extreme, large incinerators frequently use automatic systems employing load cells, electronic relay, and printed output. The electronic relay scales allow for greater flexibility in locating the scale platform in relation to the scale house. Highly automated electronic scales and recorders are more costly than simple beam scale; however, they are justified in many cases because they are faster and more accurate.

Size and Capacity. The scale should have sufficient capacity to weigh the largest vehicle anticipated to use the incinerator on a routine basis. The platform should be long enough to accommodate simultaneous weighing of all axles. Separate axle loading scales, although less expensive, are inherently inaccurate and slow in operation. For simultaneous weighing of all axles, the majority of collection trucks could be accommodated with a 10- by 34-ft platform.[1] A 50-ft platform will accommodate most trailers and semitrailers. Scales should be capable of weighing loaded vehicles of up to 30 tons.

Accuracy. The accuracy and internal mechanism of the scale and recording mechanism should meet the commercial requirements for the State or other jurisdictions involved. This is particularly necessary if user fees are based on weight.

Recommended scale requirements have been outlined by the National Bureau of Standards.[2]

Since municipal records are seldom kept closer than to the nearest tenth of a ton, and since most applied loads are within a range of 8 to 14 tons, scale accuracy of ±1.0 percent is reasonable. All scales should be periodically checked and certified to 1 percent accuracy.

Both mechanical and electronic scales should be tested under load during a quarterly inspection. This testing should include: (1) checking for a change in indicated weight as a heavy load is moved from the front to the back of the scale; (2) observing the action of the dial during weighing or for an irregularity or "catch" in dial motion; and (3) testing the scale with test weights.

Platform. The platform or deck of a scale may be constructed of wood, steel, or concrete. Wood decks are least expensive, but least durable. Many large truck scales have a platform constructed of reinforced concrete.

Scale Pit. Scale-pit walls are usually concrete and should be set in a suitable foundation to control settlement. A paved scale-pit floor facilitates cleaning and maintenance. In all cases, scale-pit drainage is essential. Scale-pit depth should be sufficient to allow periodic inspection and maintenance of the scales. Access to the pit should be through the wall or through a hatch on the platform. Gutters around the edge of the scale pit to intercept runoff from the deck have been used effectively to ensure a dry, clean scale pit. Lighting should be provided to aid in inspecting and maintaining the scale mechanism and in cleaning the scale pit.

Operation and Maintenance of Scales

Operation. The number of vehicles that can be weighed per unit time will vary with the weighmaster, automation, and amount of data to be collected. Under some conditions, an experienced weighmaster may be able to manually record, for short periods of time, the net weight and type of material at a rate of 60 trucks per hr. This rate may decrease to as few as 10 to 20 trucks per hr, however, under other conditions. A highly automated weighing procedure can easily maintain a rate of over 60 trucks per hr, record more data, require less supervision, and be more accurate. Incinerators with a capacity of 1,000 tons or more per day will usually require two or more scales.

Tare Procedures. Net weights of waste loads require subtracting vehicle tare weights from the gross weights of the loaded vehicles. This process can be performed in several ways. (1) In the case of a small incinerator with relatively few incoming loads each day, the vehicle can be weighed when full and when empty. (2) At other plants, particularly where access to the scale prevents double weighing, it would be simpler to make a list of the vehicles regularly delivering waste to the facility along with their tare weights. After each transaction or at the end of the day or week, the tares can be subtracted to provide net weights. In this system, it would be necessary to weigh up and record the tare weights of the vehicles only for the purpose of an accurate list. (3) Some automated electronic scale systems include devices for automatically subtracting the tares and providing written records of net load weights. In such systems, each vehicle must have been weighed up empty to provide a tare value, which is then recorded on a credit card or a tare key carried by the vehicle operator and inserted in the scale mechanism at the time of the scale transaction. (4) The most accurate and most secure system of obtaining net weights is through a two-scale system at each plant with fully-controlled access. One scale would weigh in the loaded vehicles; the other would weigh out the empty vehicles.

Except when vehicles are weighed twice, recorded tare weights are subject to adjustment due to several factors. Equipment may be added or removed from a truck. Such a change in tare weights can only be detected by periodically reweighing the empty truck.

Fuel errors can be reduced by checking the tare weights when fuel tanks are half full. Errors resulting from the weight of collection personnel can be avoided by using a fixed procedure whereby personnel are always on or off the scale during weighing operation.

Maintenance. Unless misused, motor-truck platform scales require little maintenance. Periodic inspections will ensure the proper functioning of the scale. To protect the scale from rust, the pit should be kept dry and the metal parts of the structure should be undercoated. If competent employees are not available for scale maintenance, a contract repair and maintenance program should be considered.

Good housekeeping in the pit will reduce maintenance and repairs of the levers in a mechanical scale. The knife edges at the pivots of a mechanical scale should be cleaned and greased at least annually. The pivots and levers should be inspected at least every 3 months to ensure freedom from obstruction, wedging, and jamming, and alignment of levers and position of pivots; nose irons should be checked during the inspection. The gap around the scale platform should be checked daily for obstruction. An all-electronic scale requires less maintenance in the pit, but more electronic maintenance aboveground.

Problems. Although a seemingly simple operation, many problems are encountered in weighing. The first is bypassing the scale. Loaded trucks may bypass the scale during the confusion of peak unloading periods and during unattended periods. To prevent this, elaborate controls and accounting techniques have been developed. A two-gate system (one at the front end and one at the back of the scale) for locking a truck on the scale until weighed, signal lights, curbing, alarms, automated recording devices, one-way exit barricades, weighmaster keys or cards for fixing responsibility of transaction, multicopy weight tickets, and simultaneous transmission of weighing information to a central computer are all being used to ensure accurate weighing of every incoming load.

Misplacement of the truck on the platform can cause errors when an axle is off or only partially resting on the scale. Suitable curbing, markings, elevated transverse bumps, or extra long scales can reduce or prevent unintentional misplacement of the vehicles on the scale.

Dirt, water, snow, and ice may accumulate on and under the deck and cause wearing and rusting of the scale, hazardous driving conditions, and errors in the payload. Cleaning the truck platform and removing accumulated material will help alleviate these problems. The top surface of the deck may be crowned or pitched 1/16 to 1/8 in. per ft transversely to improve runoff. Imbedded heating elements may be used to prevent buildup of ice and snow.

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CHAPTER VII

RECEIVING AND HANDLING SOLID WASTE

Solid waste is delivered, usually during the day shifts, in several types and sizes of trucks and vehicles. The vehicles are first weighed and then proceed to the tipping area. At large installations, the trucks unload into a storage pit, whereas at small incinerators, the practice has been to dump the waste directly into the furnace charging hopper or onto the tipping floor.

After the waste have been unloaded into the storage pit, the material must be transferred to the charging hopper. For incinerators with charging hoppers located above the storage pit, the transfer is usually performed by overhead cranes. Some incinerators have the charging floor on the same level as the storage area, and transferring is usually done with a front-end loader or special equipment.

The solid waste is charged into the furnace by dropping it directly through a gravity chute or pushing it into the furnace with a ram. After deposition, the waste is mechanically moved through the furnace.

Tipping Area

The tipping area is the flat area adjacent to the storage pit or charging hoppers where trucks maneuver into position for dumping (Figure 4). The area should be large enough to allow for safe and easy maneuvering and dumping.

Dimensions. Collection trucks tend to arrive at the incinerator in large numbers during a short time interval. To avoid a backup of trucks, the length of the tipping area and storage pit should receive careful design consideration. The total length of the tipping area should extend the length of the storage pit and, if possible, beyond the pit. Width of individual dumping spaces along the pit should be about 10 to 12 ft. These spaces should be clearly marked. Support columns should be placed to avoid interfering with dumping spaces.

The tipping area width should be greater than the turning radii of trucks using the tipping area. For single chassis compactor

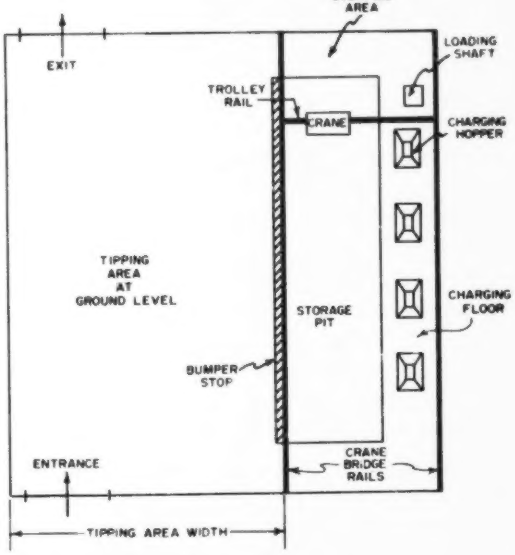

Figure 4. Plan of tipping area and storage pits with crane.

trucks, the radius is between 25 and 35 ft; for tractor trailers the radius is between 35 and 50 ft. The minimum recommended width of the tipping area is 50 to 70 ft; if the space is available, the width should be larger.

The entrance, exit, and ceiling of an enclosed tipping area must be high enough to provide the necessary clearance for dump trucks. Ceiling height is critical at the edge of the tipping area when the packer and dump bodies are raised in the unloading position. A minimum of 24 ft is recommended, but greater vertical clearance may be necessary for some trucks.

Vehicle entrances and exits should provide a minimum of 18 ft of vertical clearance. Exits should be provided with warning devices, such as hanging chains, to prevent careless drivers from attempting to exit with raised dump bodies. The entrance and exits should be equipped with wheel guards to protect the door jambs.

Tipping Floor Enclosure. Enclosing the tipping area should be considered. Climatic conditions may make it desirable. In addition, an enclosed tipping area is definitely recommended for good public relations. Dust control, odor confinement, and noise reduction effected by enclosure will help make the incinerator more acceptable to the community.

Other Aspects of Tipping Area Design. The floor of the tipping area should be constructed to withstand the heavy loads placed on it; it should slope away from the storage pit toward a drain so that the area can be regularly cleaned and flushed. The floors are usually rough surfaced for traction.

Because of the debris that accumulates in the tipping area, the drainage system is required to accommodate large quantities of wash water. The size of the receiving sewer is critical if the discharge is to such a system. Bar grates or other suitable devices can be used to prevent large objects from being discharged to the sewer and possibly obstructing flow.

Scattered dust and litter from the dumping, recasting, and charging operations are problems common to solid waste handling. Provisions for cleaning the tipping area should be considered during the design phase. Vacuum cleaning facilities, a compressed air system for cleaning electrical contacts, powered mobile sweepers, and flushers have been successful in controlling the spread of dust and litter.

Because of dangers involved in the handling and dumping of large trucks in close quarters, safety in the tipping area should be stressed by the incinerator supervisor. Hold-down chains or bumper picks are sometimes employed to prevent trucks from being tipped into the pit; however, use of these safeguards is time consuming, and short ramps sloping away from the storage pit at an angle of 8° to 12° from the horizontal will prevent mishaps efficiently.

Most plants are constructed with a curb or backing bumper along the entire length of the pit to prevent trucks from backing into the pit. This barrier must be high enough to prevent trucks from overriding, yet low enough to permit the chassis overhang to clear the curb. A height of about 1 ft is considered adequate. The face of the backing bumper is usually vertical or slightly concave to conform to the shape of the wheel. The barrier must be durable enough to withstand repeated impact and must be securely anchored to prevent movement. It should contain openings so that spilled waste can be shoveled or swept from the tipping floor into the pit.

Other measures to be considered for the safe operation of a tipping area are: (1) designing tipping area, storage pit, and crane to eliminate possibility of crane bucket striking extended dump body; (2) using a traffic director at larger incinerators; (3) permitting the dump bodies of packer trucks to be raised only when the truck is in the unloading space.

Storage Pit

The purpose of the storage pit is to provide a safe and convenient holding place for solid waste before it is charged to the incinerator. In a properly designed storage pit, waste from numerous sources can be mixed to provide a more uniform feed for the furnaces.

Capacity of the Storage Pit. When the rate of receipt of solid waste exceeds the burning rate, material must be stored for future processing. The total space for storage depends upon the amount of material remaining after the daily receiving period and the amount that is left unburned from day to day during times of peak waste delivery. The storage pit is usually designed to contain about 1.5 times the 24-hr capacity of the incinerator. If heat recovery is practiced, the pit storage capacity should receive special study to ensure a supply of solid waste adequate to meet the heat demand when waste is not delivered to the incinerator.

To calculate the necessary storage volume, the unit weight of solid waste in the storage pit must be known. The generally accepted average unit weight of waste in a storage pit is about 350 lb per cu yd.

When designing storage pits, future changes in waste density should be considered. As noted, in recent years, solid waste density has been decreasing.

Other Aspects of Storage Pits. Storage pits are usually rectangularly shaped because of crane design and ease of construction. A rectangular pit allows the crane supports to be constructed with the use of the existing pit walls and bracing. Some pits are divided into separate rectangular units with charging hoppers between units. With this design, a fire that may start in a pit can be isolated, and pit cleaning is facilitated because of the ability to alternately empty the pits.

The width of a storage pit usually does not exceed 30 ft. Minimum width is usually 15 to 20 ft or wide enough to allow a monorail crane to operate without being obstructed by the overhang of trucks in the dumping position.

The walls of the pit must withstand the external forces caused by water and soil and the internal pressures of solid waste and water in the pit, a condition that could occur during pit fires. During crane operations, the crane bucket may collide with the wall and crush the concrete. Continuous steel plating or embedded steel T-sections in the concrete can protect areas of the pit subject to repeated impact.

Fires occasionally develop in the pit. They can be caused by sparks carried over by the crane during the charging operation, from live coals in the collected waste, or spontaneous combustion of stored waste. Smoke and heat can damage the crane, break windows, and ruin equipment. Crane damage can put the entire plant out of operation for weeks or longer. The pit area should be equipped with an adequate number of fire hoses of effective size. The dewatering facilities must be adequate for the expected quantities of water used in fire fighting. Portable pumps help to remove excess amounts of water.

The entire pit should be watertight and sloped to troughs and drains for dewatering. When a pit is constructed below grade, it will usually be necessary to have a sump. Screening devices to prevent material from entering the sump are also recommended.

The sources of water and the resulting quantities vary with the installation. When pits are not watertight, leakage can occur as a result of the positive hydrostatic pressure of groundwater. Waste collected in wet weather may be saturated, and vertical drainage will occur in the pit. Water from dust control sprays also enters the pit.

Cleanout facilities are needed to empty the pit if the furnace equipment breaks down or to remove unwanted items inadvertently unloaded into the pit and remove saturated waste after a fire. A loading shaft from the charging floor to the ground level is useful for unloading the pit and for hoisting heavy equipment and material from ground level to the charging floor (Figure 4).

Charging Methods

Solid waste is charged into the furnace by several methods. In small installations where the storage area is on the same elevation as the charging hoppers, a front-end loader, vibrating hopper and conveyor, or other mechanical means are used. At larger incinerators, cranes charge the solid waste.

Besides transporting solid waste to the charging hoppers, cranes also mix and distribute the solid waste in the pit. This action results in a more uniform burning material and better utilization of pit capacity.

Crane Types. The types most commonly used are the monorail crane and the bridge crane (Figure 5). The former is a fixed unit suspended from a single rail that crosses the pit in only one horizontal direction. The bridge crane differs from the monorail in that it can maneuver horizontally in two directions rather than one. The capacity of the monorail crane is usually less than that of a bridge crane; the width of the storage pit is restricted to include only that lateral area within reach of the open bucket. Capital cost of a monorail crane is less than that of a bridge crane, and at some incinerators, its performance may be adequate.

Crane Capacity and Bucket Design. The size of crane needed to operate an incinerator is a function of incinerator capacity. Each continuous-feed-type furnace requires a given number of bucket loads at regular intervals. The size of the bucket, therefore, is a function of the 24-hr furnace capacity and number of bucket loads per 24 hr. Once the size of bucket has been fixed, the crane capacity can be specified. For example, a 4.5-ton crane is recommended for use with a 2.5-cu-yd bucket.

The number of bucket loads that can be charged during a given period depends upon the number of cycles that the crane can make during the charging operation. A cycle is defined as the time for loading and lifting the bucket, trolleying and bridging to the charging hopper, dumping, and returning for another bucket load. Typical cycles vary from 1-1/2 to 3 min. To determine the cycle time, the hoisting, bridging, and trolleying speeds must be known, as well as the length, width, and depth of storage pit. Typical hoisting and trolley speeds are between 250 and 300 ft per min, whereas bridge travel speeds may be as high as 350 ft per min. In general, design criteria does not require high speeds.

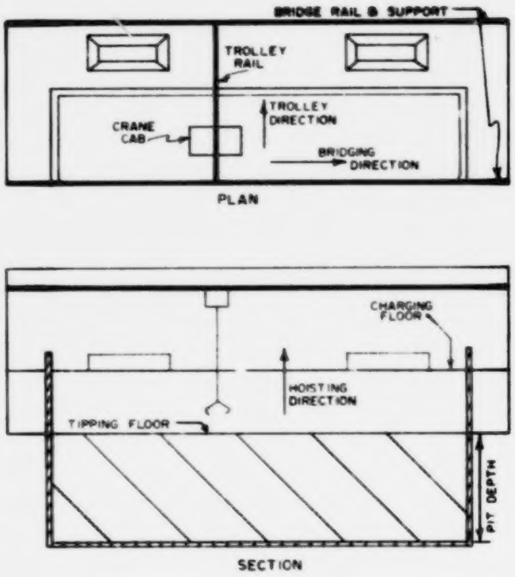

Figure 5. Plan view and section view of bridge crane.

Incinerator cranes usually use the closed scoop bucket or a grapple. The closed scoop is a clamshell with heavy steel lips usually equipped with short teeth to increase penetrating ability. The grapple type is similar to a clamshell but has much longer teeth, called tines. This type has a considerably larger capacity than an equally rated closed scooped bucket. The grapple is a poor cleanup tool because of the length and spacing of its tines. For cleaning purposes, the grappple can be equipped with bolted-on pans.

Number of Cranes. Crane downtime will stop incinerator operations unless a standby crane is provided. Nearly all installations with a capacity above 400 tons per day (TPD) have a second crane to prevent shutdowns. A second crane is recommended for plants with over a 300-TPD capacity. Because of high costs, most small plants have only one crane. At larger installations, a third crane is often justified, and nearly 50 percent of the plants with over a 850-TPD capacity have three cranes. With a second or third crane, space in addition to the operating space required for the first crane must be provided for the storage of the units when not in service. The point of storage for the nonoperating units must not interfere with the operating unit.

Control and Operation. The crane can be operated manually from a cab traveling with the crane or form a remote fixed operating point. Manual operation form a mobile cab has some advantage over a remote fixed operating point. The operator has better visibility, which usually yields better and safer operation. Where the pit is long, the distance judgment error is reduced with mobile cab operation.

When a mobile cab is used, the operator should have a safe convenient boarding platform. Since the charging operation may be dusty and hot, the crane cab should be air-conditioned.

Charging Hoppers

Charging hoppers are used to maintain a supply of solid waste to the furnace. In batch-feed furnaces, a gate separates the charging hopper from the furnace and supports the solid waste while the furnace is burning the previous charge. Generally one hopper is provided for each furnace cell. In a continuous-feed furnace, the waste-filled hopper and chute assist in maintaining an air seal to the furnace as well as to provide a continuous supply of solid waste.

Most charging hoppers have the shape of an inverted, truncated pyramid. The size of the hopper opening depends somewhat upon the size of the furnace, but it should be large enough to prevent arching of oversized material across the hopper bottom. Common hopper openings measure from 4 X 4 ft to 4 X 8 ft. The hopper should be deep enough to receive a bucketful of solid waste without spilling over.

The charging hopper is generally steel and sometimes concrete lined. Because of abrasion from solid waste, impact from the crane bucket, and heat from the furnace, the hopper must be constructed of rugged material and built to facilitate repair and replacement.

Charging Chutes

The charging chute connects the hopper to the furnace and may be nearly as wide as the furnace so that the solid waste will pass through the chute without clogging. The discharge of waste into the furnace is usually by gravity, but reciprocating or vibrating feed mechanisms may also be used. Several measures may be taken to prevent solid waste's tendency to clog chutes. These are use of: smooth inside surfaces; corrosion resistant materials; vertical (or nearly vertical) chutes with increasing cross section.

The charging chute, because of its proximity to the furnace, should be protected against extreme heat. For this reason, chute walls are often water jacketed. A hopper cover or other means of closure should be provided for ending a burning cycle in continuous-feed furnaces.

CHAPTER VIII

FURNACES AND APPURTENANCES

Incineration is a controlled combustion process for burning solid, liquid, or gaseous combustible waste to gases and to a residue containing little or no combustible material. When solid waste is exposed to a turbulent atmosphere for a critical time period at an elevated temperature, combustion occurs. During combustion, moisture is evaporated, and the combustible portion of the solid waste is vaporized and then oxidized. Concurrent reactions are the oxidation of metals and the oxidation of such elements as sulfur and nitrogen. Carbon dioxide, water vapor, ash, and noncombustibles are the major end products of combustion.

The combustion processes take place in the furnace of the incinerator, which includes the grates and combustion chambers. There are numerous designs or configurations of furnaces to accomplish combustion, and, to date, no one design can be considered the best.

Furnaces

Furnaces commonly used for the incineration of municipal solid waste are the vertical circular furnace, the multicell rectangular furnace, the rectangular furnace, and the rotary kiln furnace.[1] Although these furnaces vary in configuration, total space required for each is based on a heat release rate of about 18,000 Btu per cu ft of furnace volume per hr, although heat release rates varying from 12,500 to 25,000 Btu per cu ft per hr have been used.

The vertical circular furnace is usually refractory lined. Solid waste is charged through a door or lid in the upper part (usually the ceiling) and drops onto a central cone grate and the surrounding circular grate (Figure 6). Underfire forced air is the primary combustion air and also serves to cool the grates. As the cone and arms rotate slowly, the fuel bed is agitated and the residue works to the sides where it is discharged, manually or mechanically, through a dumping grate on the periphery of the stationary circular grate. Stoking doors are provided for manual agitation and assistance in residue dumping if required. Overfire air is usually introduced to the upper portion of the circular chamber. A secondary combustion chamber is adjacent to the circular chamber. Many furnaces of this design are in operation.

The multicell rectangular type, also called the mutual assistance furnace, may be refractory lined or water cooled; it contains two or more cells set side-by-side, and each cell normally has rectangular grates (Figure 7). Solid waste is usually charged through a door in the top of each cell. Generally, the cells of the furnace have a common secondary combustion chamber and share a residue disposal hopper.

The rectangular furnace is the most common form in recently constructed municipal incinerators (Figure 8). Several grate systems are adaptable to this form. Commonly, two or more grates are arranged in tiers so that the moving solid waste is agitated as it drops from one level to the next level. Each furnace has only one charging chute. Secondary combustion is frequently

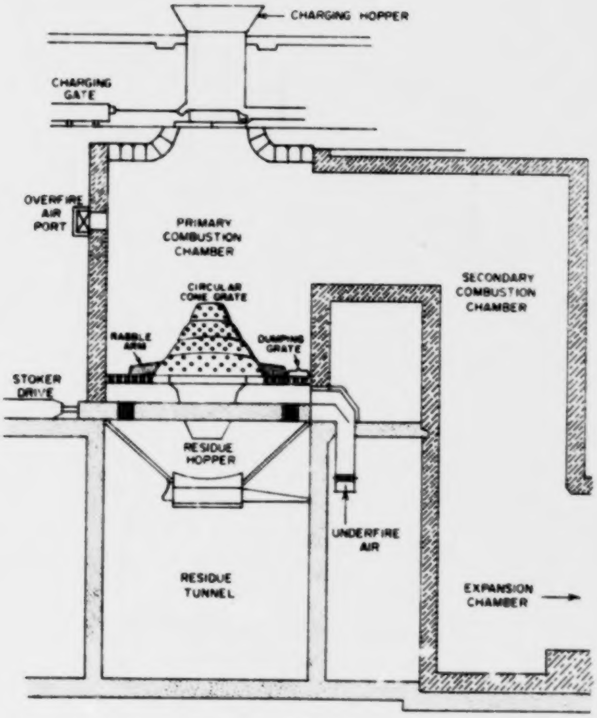

Figure 6. Vertical circular furnace.

A rotary kiln furnace consists of a slowly revolving inclined kiln that follows a rectangular furnace where drying and partial burning occurs (Figure 9). The partially burned waste is fed by the grates into the kiln where cascading action exposes unburned material for combustion. Final combustion of the combustible gases and suspended combustible particulates occurs in the mixing chamber beyond the kiln discharge. The residue falls from the end of the kiln into a quenching trough.

Grates and Stoking. The grate system must transport the solid waste and residue through the furnace and, at the same time, promote combustion by adequate agitation and passage of underfire air. The degree and methods of agitation on the grates are important. The abrupt tumbling encountered when burning solid waste drops from one tier to another will promote combustion. Abrupt tumbling, however, may contribute to entrainment of excessive amounts of particulate matter in the gas stream. Continuous gentle agitation promotes combustion and limits particulate entrainment. Combustion is largely achieved by air passing through the waste bed from under the grate, but excessive amounts of underfire air contribute to particulate entrainment.[2] Some inert materials, such as glass bottles and metal cans, aid combustion by increasing the porosity of the fuel bed. Conversely, inert materials inhibit combustion if the materials clog the grate openings. Mechanical grate systems must withstand high temperatures, thermal shock, abrasion, wedging, clogging, and heavy loads. Such severe operating conditions can result in misalignment of moving parts, bearing wear, and warping or cracking of castings.

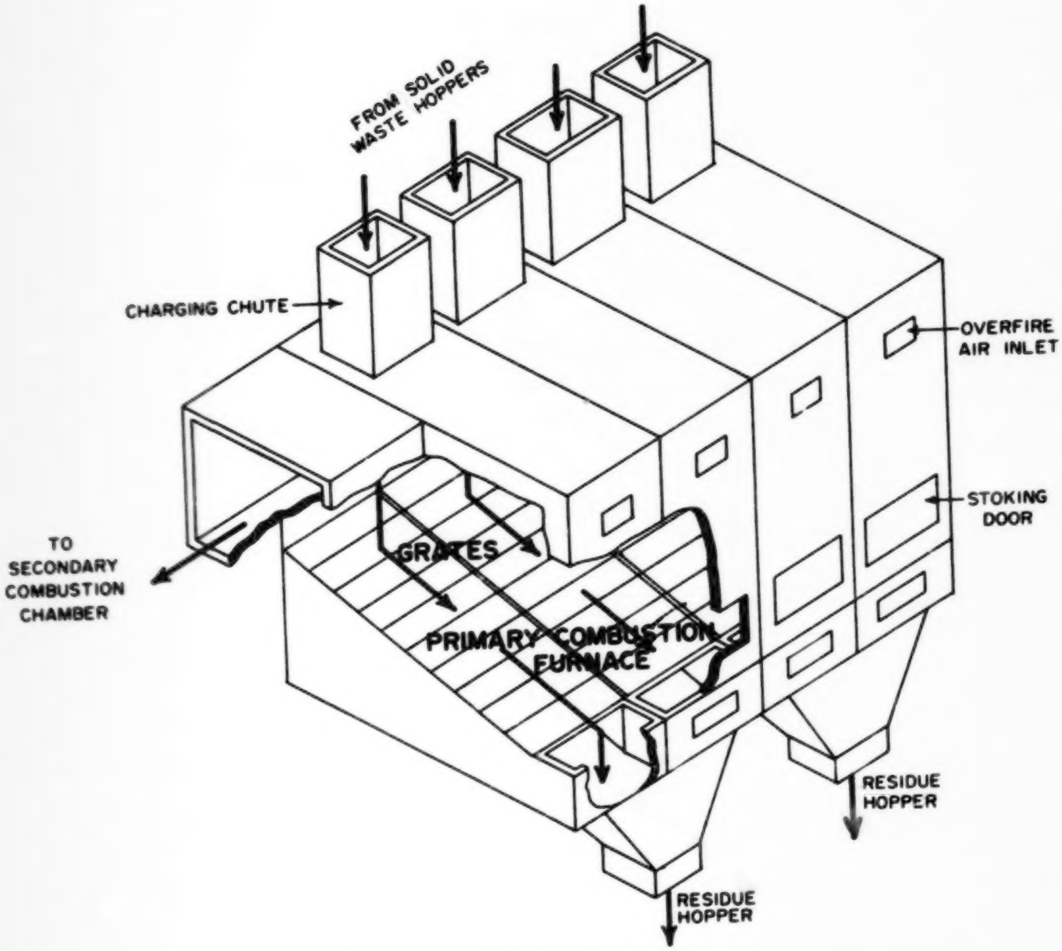

Figure 7. Multicell rectangular furnace

For design purposes, the required grate area is approximated by dividing lb per hr solid waste to be burned by the lb per sq ft per hr solid waste the grates are capable of burning. Ordinarily, the design value for the grate loading will be between 50 and 70 lb per sq ft per hr. This design value depends mostly on type of solid waste and grate design, but also depends on the other elements of the furnace. The grate loading is often expressed in Btu's per sq ft per hr. An average rating of 300,000 Btu per sq ft grate per hr is often used as a design parameter.

Grate systems may be classified by function, such as drying grate, ignition grate, and combustion grate. Grates for solid waste incineration may also be classified by mechanical type. They include traveling, reciprocating, rocking, rotary kiln, circular, vibrating, oscillating, and reverse reciprocating grates; multiple rotating drums; rotating cones with arms; and variations or combinations of these types. In the United States, traveling, reciprocating, rocking rotary kiln, and circular grates are the most widely used.

Traveling grates are continuous, belt-like

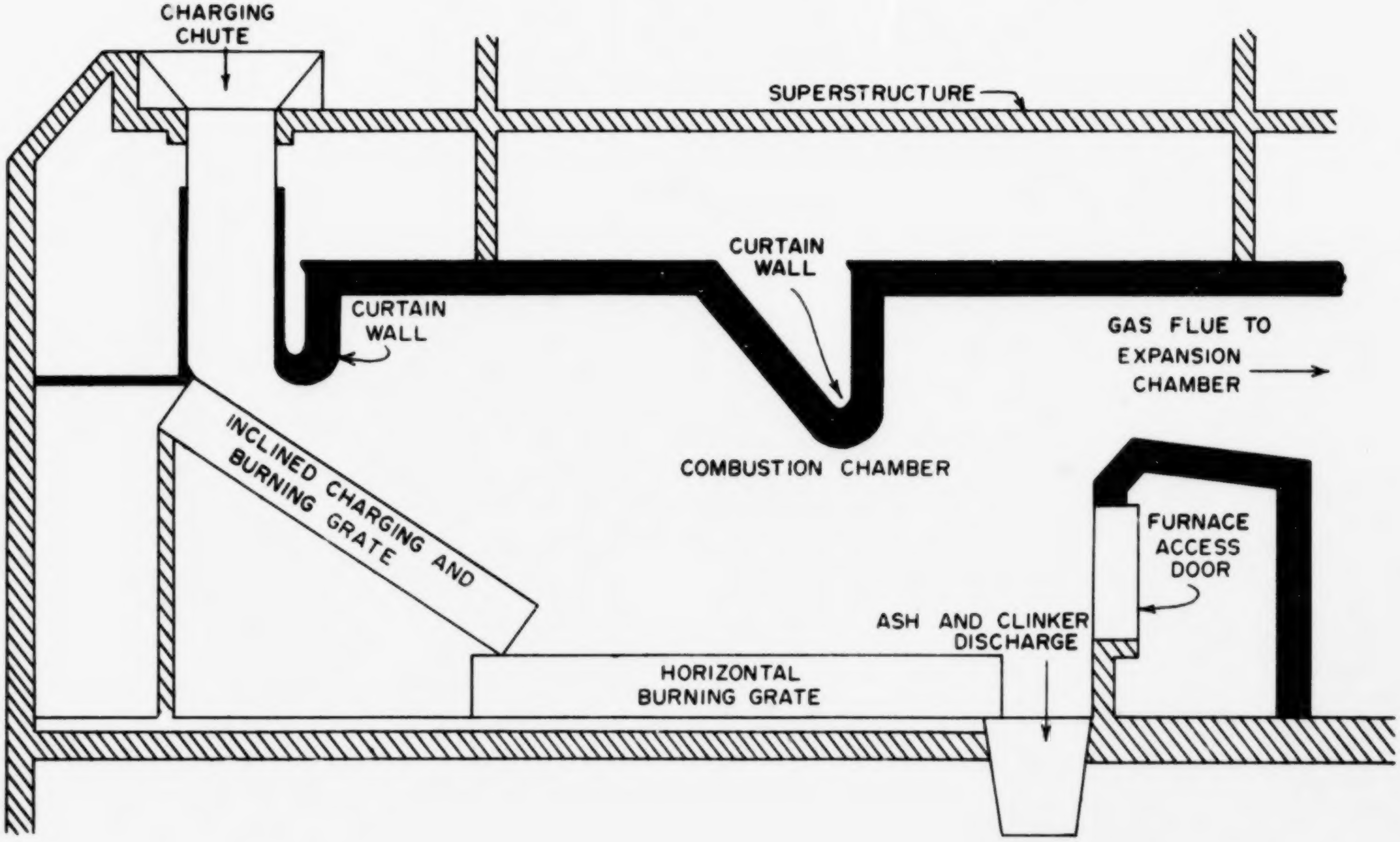

Figure 8. Rectangular furnace.

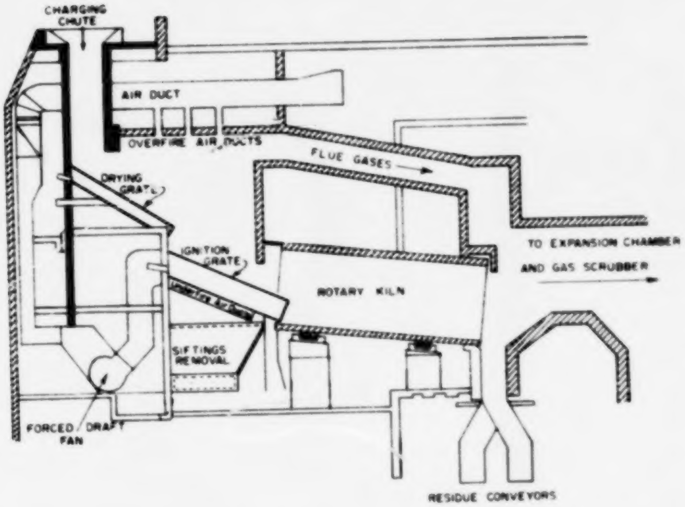

Figure 9. Rotary kiln furnace.

conveyors (Figure 10). A single traveling grate does not promote agitation. Two or more grates at different elevations provide some agitation as the material drops from one level to the next.

In reciprocating grate systems, the grate sections are stacked like overlapping roof shingles (Figure 11). Alternate grate sections slide back and forth while adjacent grate sections remain fixed. Like traveling grates, reciprocating grates may be arranged in multiple-level series providing additional agitation as the material drops from one grate to the next.

Rocking grates are arranged in rows across the width of the furnace, at right angles to solid waste flow. Alternate rows are mechanically pivoted or rocked to produce an upward and forward motion, thus advancing and agitating the solid waste (Figure 12). Rocking grates have also been arranged in series.

The rotary kiln has a solid refractory surface and is commonly preceded by a reciprocating grate. The slow rotation of the kiln, which is inclined, causes the solid waste to move in a slowly cascading and forward motion.

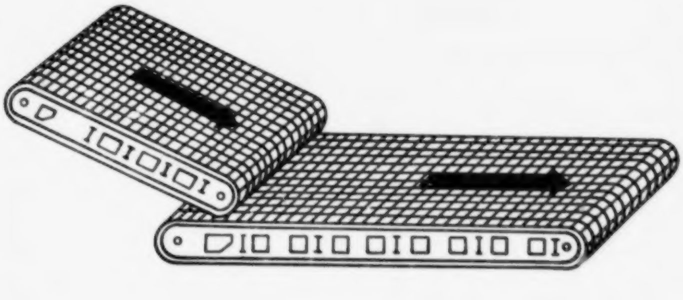

Figure 10. Traveling grates.

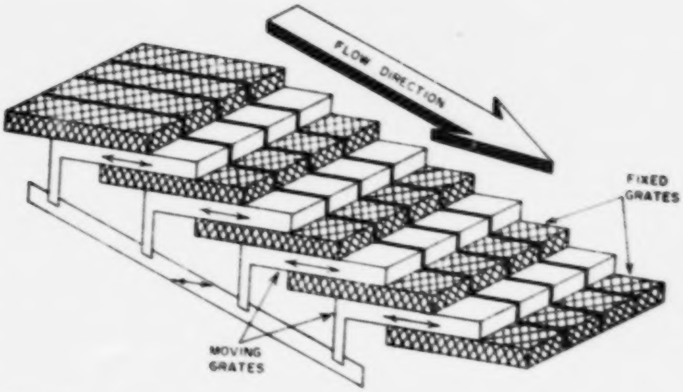

Figure 11. Reciprocating grates.

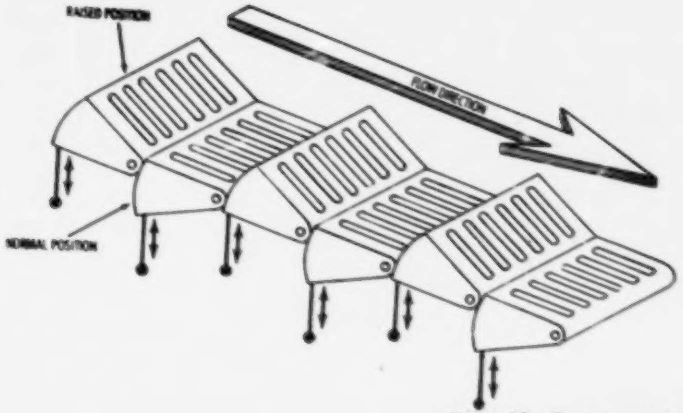

Figure 12. Rocking grates.

The circular grate, in the vertical circular furnace, is commonly used in combination with a central rotating cone grate with extended rabble arms that agitate the fuel bed (Figure 13).

Charging Solid Waste. Solid waste is charged either continuously or in batches. In the continuous process, solid waste is fed to the furnace directly through a rectangular chute that is kept filled at all times to maintain an air seal. In the batch process, solid waste is fed to the furnace intermittently through a charging gate or hatch, which is closed except when waste is being charged. The waste may be stored in a hopper and fed intermittently through a chute, or the furnace may be fed directly by opening the charging gate and dropping the waste directly from a crane bucket, front-end loader, or bulldozer. A ram can also be used to feed a batch of material directly to the gate through an opening in the furnace wall. Continuous feed minimizes irregularities in the combustion system. Batch feeding causes fluctuations in the thermal process because of the nonuniform rate of feeding and intermittent introduction of large quantities of cool air.

Siftings Removal. Siftings are the fine materials that fall from the fuel bed through the grate openings during the drying, ignition, and burning processes. Siftings consist of ash, small fragments of metal, glass and ceramics, and unburned or partially burned organic substances. In some designs, siftings are collected in troughs and conveyed continuously by sluicing or mechanical means to a residue collection area. In other designs, siftings are collected and returned continuously by a conveyor to the furnace.

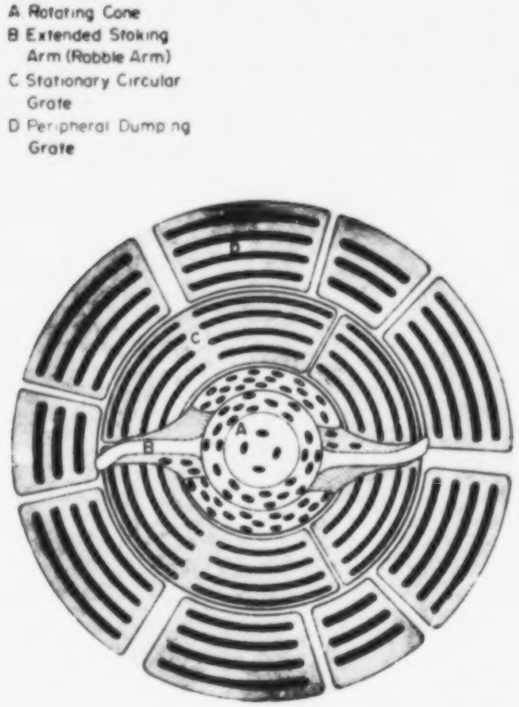
A Rotating Cone
B Extended Stoking Arm (Rabble Arm)
C Stationary Circular Grate
D Peripheral Dumping Grate
D
C
B
A

Figure 13. Circular grates.

Siftings may also be removed by the batch method. If siftings containing highly combustible materials such as oil, plastics, and grease, accumulate, unquenched, beneath the grate, they can burn and cause heat damage to the grates above.

Residue Removal. Residue—all solid materials remaining after burning—includes ash, clinkers, tin cans, glass, rock, and unburned organic substances. Residue removal can either be a continuous operation or an intermittent batch process. In a continuous feed furnace, the greatest volume of residue comes off the end of the burning grate; the remainder comes from siftings and from fly ash (Chapter XII). The residue from the grate must be quenched and removed from the plant.

Batch operated furnaces usually have ash collection and storage hoppers beneath the grates. Periodically, residue is removed, quenched, accumulated in a residue hopper, and discharged from the bottom by opening a watertight gate. Discharge may be placed into trucks or other containers for transport to a disposal area. Access to the residue hoppers is usually by a tunnel beneath the furnace floor. Ash tunnels should be wide enough to allow an employee to safely walk past a vehicle. The tunnel should be paved, well drained, and well lighted. Provisions should be made for adequate ventilation and dust removal. Excess quench water should be drained before trucks are loaded, and the residue trucks or containers should be watertight. Residue trucks dripping quench water to the disposal site are unsightly, insanitary, and they invite complaints from the community.

In many continuous feed operations, residue is discharged continuously into a trough or troughs connected to all furnaces. A slow-moving drag conveyor, submerged in the water-filled trough, continuously removes the residue. Usually the discharge end of the conveyor is inclined to allow drainage of excess quench water from the residue before loading into a holding hopper or directly into trucks. The residue conveyor system must be ruggedly constructed to withstand heavy loads and continuous use. The residue is highly abrasive, and the quench water is highly corrosive. Since the residue is discharged to the conveyor below water, this system has the advantage of maintaining an air seal to the furnace. For continuous, dependable operation, a dual conveyor system is justified in plants above 250-TPD capacity.

Combustion

Time, temperature, and turbulence are commonly called the three T's of combustion. When solid waste is exposed for a sufficient time to a turbulent, hot atmosphere, the waste will be satisfactorily incinerated.

For a substance to burn, both surface and internal moisture must be driven from the material. The vaporization of moisture present in waste material will keep the temperature of the material below 212 F. Once moisture is removed, the temperature of the substance can be raised to the ignition point, although the outer surface of a solid may be dried and ignited before the inner material is dried. This drying process continues throughout the entire length of the furnace, but proceeds at the greatest rate immediately following charging of the solid waste.

To facilitate drying, some furnace designs use preheated air or incorporate reflecting arches to radiate heat stored from the burning of previously charged material. The first part of the grate system is also frequently referred to as the drying grate. Ignition takes place as the solid waste is dried and continues through the furnace. The portion of the grates where ignition first occurs is often called the ignition grate.

The combustion process in incineration is thought of as occurring in two overlapping stages, primary combustion and secondary combustion. Primary combustion generally refers to the physical-chemical changes occurring in proximity to the fuel bed and consists of drying, volatilization, and ignition of the solid waste. Secondary combustion refers to the oxidation of gases and particulate matter released by primary combustion. Secondary combustion achieves combustion of unburned furnace gases, elimination of odors, and combustion of carbon suspended in the gases. To promote secondary combustion, a sufficiently high temperature must be maintained, sufficient air must be supplied, and turbulence or mixing should be imparted to the gas stream.

The function of turbulence is to ensure mixing of each volume of gas with sufficient air for complete burning of volatile combustible matter and suspended particulates. The turbulence must be intense and must persist long enough for mixing to be completed while the temperature is still high enough to ensure complete burning.

Introduction of Air to the Furnaces. In the combustion process, oxygen is needed to complete the chemical reaction involved in burning. The air necessary to supply the exact quantity of oxygen required for the chemical reactions is termed stoichiometric or theoretical air. Any additional air supplied to the furnace is termed excess air and is expressed as a percentage of the theoretical air.

Air that is purposely supplied to the furnace from beneath the grates is termed underfire air. Overfire air is that air introduced above the fuel bed; its primary purpose, in addition to supplying oxygen, is to provide turbulence. Infiltration air is the air that enters the gas passages through cracks and openings and is frequently included in the figure for overfire air.

The proportioning of underfire air and overfire air depends on incinerator design. Very often, the best proportions are determined by trial and error. For most municipal incinerator designs, underfire air is from 40 to 60 percent of the total air. (Total air is the total of all underfire, overfire, and infiltration air.) This amount of underfire air air provides acceptable combustion in the fuel bed and adequate grate cooling. In general, as the underfire air is decreased, the burning rate is inhibited.

To supply adequate air for complete combustion and to promote turbulence, a minimum of 50 percent excess air should be provided. Too much excess air, however, can be detrimental because it lowers furnace temperatures. In general, refractory furnaces require 150 to 200 percent excess air, whereas water tube wall furnaces require only 50 to 100 percent excess air.

Gas Flow from Furnace. The burning of solid waste generates heat that expands the volume of gas. The gas passages, air pollution control devices, and stack must satisfactorily accommodate this gas. An estimate of the quantities of gaseous products of combustion can be calculated from the ultimate analyses of solid waste. Gas velocities must be determined so that gas passages can be sized to prevent excessive settlement of entrained particles.

Incinerator stacks provide natural draft and dispersion for gases and particulate matter. Accordingly, the height and diameter of the stack depend upon the amount of draft required and the topographic and climatic conditions. If necessary, induced draft fans should be used to supplement the natural draft in moving gases through the incinerator. The decision to use a tall stack with natural draft only, a short stack that relies principally upon induced draft, or a combination of these should be made by the designer after careful consideration of ambient air quality, health effects, Federal Aviation Agency regulations, architecture, and other constraints.

To adequately control the combustion process, the draft must be regulated. Dampers are generally used in both natural draft stacks and in stacks employing induced draft fans of constant speed. Adjustable speed, induced draft fans are also used to control draft. Under most conditions, an induced draft fan is preferred over natural draft stack. Control over the burning solid waste can be better maintained and air pollution collection devices better operated with the constant air volume and uniform pressure drop that the induced draft fan creates.

Combustion Temperature and Cooling

Adequate temperature, time, and turbulence are necessary to completely burn the gases and carbon suspended in the gases and to destroy the odors. If temperatures are too low, the oxidation reactions are incomplete; if too high, the temperatures can cause equipment and structural damage throughout the incinerator. Excessively high temperatures can cause refractories to fail through excessive expansion, can cause slag buildup on the furnace linings, or may produce oxides of nitrogen. When the air stream is suddenly cooled, these nitrogen oxides do not have time to decompose to nitrogen and oxygen. Because of variations in composition and density of the solid waste, careful operation is required to maintain furnace temperatures within the desirable range.

Temperature. At the air intake, combustion air is at ambient temperature. Combustion air may be preheated to 200 to 300 F. Once in the furnace, the temperature rapidly rises. Immediately above the burning waste, the temperature of the burning gases generally ranges from 2,100 to 2,500 F, and for short periods of time, it may reach 2,800 F in localized areas. When the gas leaves the combustion chamber, the temperature should be between 1,400 and 1,800 F. The gas temperature entering the stack can be expected to be 1,000 F or less. Where induced draft fans, electrostatic precipitators, and other devices requiring lower gas temperatures are used, the gases will have to be cooled further. Before they enter the air pollution control devices, the gases should be cooled to 500 to 700 F.[3]

In a batch feed incinerator, opening the charging door lowers the temperature of gases in the combustion chamber by as much as 500 F. Introducing extremely high or low Btu wastes can also cause abrupt and extreme temperature change.

Furnace temperature varies considerably, depending on where it is measured. The most widely accepted location for measuring and reporting furnace temperature is near the roof at the exit of the combustion chamber. At this location, the temperature should be maintained between 1,400 and 1,800 F to ensure that proper combustion has occurred.

Most incinerator designs are based on temperatures within the 1,400 to 1,800 F range. In practice, operating temperatures frequently fluctuate by 200 F or more from this design range sometimes in a matter of minutes. The furnace temperature should be maintained at fairly constant levels, preferably in midrange. Such operation will accommodate sudden temperature changes within the 1,400 to 1,800 F range. In some cases, auxiliary fuel will be needed to maintain satisfactory temperature.

Methods of Cooling the Furnaces and Flue Gas. Regulation of the combustion process through control of furnace and flue gas temperatures is achieved principally through the use of excess air, water evaporation, and heat exchange. Of these, the use of excess air is the most common and, in refractory furnaces, is often the only method of control. Even when another cooling method is available, some excess air is still used but primarily for ensuring turbulence and complete combustion.

In all incinerators, some heat is lost through the furnace walls. The amount of heat dissipated in this manner is small compared with the total heat release; however, these heat losses must be considered when designing the furnace.

The purpose of excess air is to cool and mix the hot gases through a dilution process, which lowers gas temperatures. The cooler ambient air is mixed with the hot combustion gases, and an equilibrium temperature is reached.

Water injected into the hot gas stream cools the flue gas through evaporation of the water and absorption of heat during superheating of the water vapor. Although the water vapor adds to the total gas volume in a manner similar to the addition of excess air. the total of water vapor and cooled gases is smaller than the original volume of gases. Some economy may result from reducing this volume of gas to be treated; however, the cost of water should also be considered. Water cooling is used on flue gases but is not generally employed in cooling the furnace.

Although heat exchange through the use of water tube walls and boilers is not in widespread use in the United States, it is attracting greater attention and is employed in Europe. A distinct advantage of heat exchangers in cooling gases is that additional gases or vapors are not added to the gas flow to reduce temperature and significantly smaller gas volume results. Because gas volume is greatly reduced, the size of collection devices, fans and gas passages can be reduced. Heat recovery and utilization can bring further economies.

Refractories

Refractories. materials employed to resist heat, are commonly used in incinerators to line furnaces, subsidence chambers, breechings, and stacks. Most refractories are composed wholly or in part of alumina, magnesia, and silica although chromite and zircon are common synthetic or artificial refractories. Many of these materials are interground with kaolin, the oldest and most widely used natural refractory.

Refractories are classified according to their physical and chemical properties which vary considerably.[4] Their thermal expansion characteristics, heat conductivity, hardness, strength, and chemical resistivity also vary.

Refractories are commonly precast as bricks, which are laid with mortar. They can also be used in the form of dry powder, which is mixed like cement with water and cast in forms. Plastic refractories are pre-mixed by the manufacturer with just enough water to be plastic or moldable on the job; they are used mainly as a patching material and in confined area, but have been used for complete furnace linings.

The mortars used to lay and bond refractory brick are either air setting or thermal setting. Air-setting mortars harden more or less uniformly at outside air temperature through normal hydration processes, whereas thermal-set mortars depends on the degree of heat penetration.

Refractories expand in all directions when heated; therefore, expansion joints must be provided. Failure to do so can cause a buildup of stresses that could produce cracks and in some cases even structural failure.

Furnace Walls. In the past, furnace walls were designed to conserve as much heat as possible from the combustion process. With today's higher heat value waste, the previous emphasis on conserving heat throughout the furnace has decreased. In the last 15 yr. the trend has been toward thinner (9-in.) refractory walls and away from massive fire-brick refractories. Indeed the emphasis now is on withstanding temperatures in excess of 2,000 F and on preventing refractory softening, erosion, slagging, and spalling. In areas such as the drying and ignition zone, however, where a high temperature is desired, the heat storage capacity of the walls and heat reflection continues to be important.

Furnace walls constructed with refractory linings are the most common and probably will continue to remain popular. The thinner walls of modern design are supported at frequent intervals by anchors attached to a steel superstructure that bears the majority of the refractory weight. They are therefore suspended walls rather than of conventional bearing or arch construction. The large flat roofs of most rectangular furnaces are constructed in a similar manner. Suspended furnace walls are usually a combination of insulated and air-cooled construction. Insulation reduces heat loss, maintains heat storage in low temperature zones, and protects the external parts of the incinerator from excessive heat. In high-temperature zones, insulation may be reduced or omitted with reliance on air-cooling. Suspended wall and roofs, usually with a refractory depth of 9 in., have the added advantage of permitting localized repair of damaged areas. In conventional bearing wall or arch construction, complete reconstruction is often required in making repairs.

The primary combustion zone is the section of highest refractory maintenance. The destructive influences on refractories are excessively high temperatures, flame impingement, thermal shock, slagging, spalling, abrasion from stoking tools and sliding or tumbling solid waste, and erosion from high velocity gases with entrained particles. Refractories of super duty or equivalent quality best meet the physical and thermal requirements as listed above.

The high abrasive areas immediately above the grate line (where slagging is also likely to occur) and the charging area frequently require a dense refractory such as silicon carbide or high alumina brick. Where lower temperatures and less wear occur as in subsidence chambers and stack, a lower quality refractory may be used. Acid-resistant refractories and mortar should be used in areas subject to corrosion.

Spalling and slagging are common forms of refractory destruction. Spalling is the breaking away of the refractory, usually of the outer surface, because of internal thermal stresses developed through differential expansion. Slagging is a form of destruction that occurs from the buildup of a layer or deposit of flux on the refractory surface. This flux is composed of oxides of sodium, potassium, iron, calcium, and other elements from the burning waste. The increased weight of this bonded and fused layer of buildup causes the refractories to fail. Failure may also be caused by differential expansion and contraction between the bonded slag layer and the refractory. Slag formation can also cause damage by interfering with grate movement. Mineralogically stable, high melting point refractories that are dense, of low porosity and high strength, are most resistant to slagging and spalling.

Water tube wall furnaces are made of closely spaced steel tubes welded together to form a continuous wall with water or steam circulating through the tubes. The water tube wall furnace offers greater control over temperatures and provides an air-tight enclosure. These furnaces have been used successfully in the power industry and in some European incinerators for many years; however, their installation in municipal incinerators in the United States has been limited.

Other Aspects

Auxiliary Fuels. It is desirable to have auxiliary fuels available for (1) furnace warm up; (2) promotion of primary combustion when the solid waste is wet or does not contain an adequate Btu content for good combustion; (3) completion of secondary combustion to ensure odor and smoke control; (4) supplementation of heat for heat recovery units when the supply or heat value of the solid waste is not sufficient.

Auxiliary fuel is usually gas or oil. Burner location depends on the purpose of the auxiliary fuel. The use of auxiliary fuel has not been common practice in the United States, and consequently, further investigations are needed to determine the best locations for auxiliary fuel burners.

Starting the Furnace. When an incinerator is started, the operating temperature of 1,400 to 1,800 F should be reached as quickly as consistent with good practice, which varies with the incinerator design and the refractories. Incinerators with induced draft fans usually reach operating temperature in less than 1 hr. Natural draft plants may require more than 4 hr. Plants with suspended wall construction require as little as half an hour for heating refractories.

If new refractories are installed, the manufacturer should be consulted for his recommendations on refractory curing and furnace preheating. To prevent damage to new refractory linings, drying or curing is usually necessary. This preheating period is long and gradual, often requiring several days.

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CHAPTER IX

RECOVERY AND UTILIZATION OF HEAT

The concept of the recovery and use of heat produced during incineration has always intrigued engineers and municipal officials. Unless the heat is used, it is wasted—either to the atmosphere or to a heat exchange system. In European municipal incinerators, the use of heat recovery equipment is now common practice. In contrast, relatively few U.S. municipal incinerators practiced heat recovery for other than in-plant use.

Because heat recovery and water cooling of incinerator furnaces reduce the volume of gas to be cleaned and hence the size of air pollution control equipment needed, they have been advocated as a means to effect possible savings in the cost of air and water pollution control equipment. The trend toward more effective and costly pollution control equipment increases the economic feasibility of heat recovery. The increased heat content of municipal solid waste also enhances the economic feasibility of heat recovery. The justification for installing heat recovery equipment in most incinerators is based on obtaining sufficient income from the sale of steam or power to offset the additional cost that results from utilizing excess heat.

Heat Recovery Systems

Heat is recovered by heat transfer from hot gases or flames to steam or hot-water systems. Four basic designs have been used: (1) waste heat boiler systems with tubes located beyond conventionally built refractory combustion chambers; (2) water tube wall combustion chambers; (3) combination water tube wall and refractory combustion chambers; (4) integrally constructed boiler and water tube wall combination.

The amount of excess air required differs significantly in the operation of these four types. Refractory-lined chambers usually require 150 to 200 percent excess air whether waste heat recovery is practiced or not. Water tube wall chambers usually need 50 to 100 percent excess air. Low excess air reduces the volume of flue gas to 50 or 60 percent of that from refractory-lined furnaces, increases recoverable heat, and reduces the size of necessary air pollution control equipment.

Any of these four systems of waste heat recovery eliminates the need for evaporating large quantities of spray water or adding large quantities of cooling air to reduce the exhaust temperature to the 600-F range needed by most air pollution equipment.

Theoretical efficiency of the recovery process may be as great as 70 percent, depending on the type of heat recovery equipment utilized. Steam production ranges from 1 to as much as 3.5 lb per lb of solid waste burned because of variations in excess heat available from the solid waste.[1,2]

Another method of heat recovery is a flue-gas-to-air heat exchange located at the exit of the incinerator chamber. This method is inefficient because the temperature of the gas-to-air exchange metal must be held at moderate levels to prolong its life. The metallic alloys necessary for a gas-to-air type of exchange are expensive and require excessive maintenance.

In heat recovery operations provisions must be made for cleaning the boiler tubes and blowing out the soot to correct the problem of tube fouling caused by fly ash deposits and, under some conditions, slagging. Increasing the space between the water tubes can reduce fly ash clogging of gas passages.

External corrosion of boiler tubes caused by chlorides and other chemicals on the fire side of the tubes will increase with the rising volume of plastics in municipal solid waste, resulting in greater maintenance costs.

Application for Recovered Heat

In the United States, most engineers hesitate to design systems to reclaim waste heat from incinerators because of the added costs of heat recovery equipment, the variability of the heat value of solid wastes, and the difficulty of matching the supply of waste heat to the demand for heat. Matching the heat output of the incinerator to the demand presents a serious problem. In most cases, other sources of steam, hot water, or electricity must be available to supply any deficiency because of either increased demand or a drop in output from the incinerator. When the demand for reclaimed heat cannot be met by the incineration of solid waste, large capacity auxiliary fuel burners located near the boiler can provide the heat recovery system with additional heat as needed. Since an incinerator must burn a daily quota of solid waste of varied heat content, the output is usually more or less than the demand. Provisions must be made, therefore, to dissipate excess heat.

Excess steam can be dissipated by heat exchange through water-cooled or air-cooled condensers. Condensers increase initial and operating costs, and exhausted steam must be replaced by treated feedwater, which increases the cost of feedwater treatment and storage facilities.

Many U.S. incinerators with heat recovery equipment use recovered heat for in-plant use only. These plants use recovered heat to generate electricity, supply hot water, and heat the incinerator plant during cold weather. Recovered heat has also been used at one plant for desalting sea water for in-plant use and for supplying steam power within the incinerator plant and to nearby sewage treatment plants.

Several U.S. incinerators supply steam to heating systems and to institutions such as hospitals. The sale of steam to power generation plants is also possible. The most practical means of using waste heat is to supply steam to a large power system with a minimum demand greater than the incinerator can produce. Under these conditions, steam does not have to be wasted when the demand is at a minimum, and fluctuations in incinerator steam production are accommodated by other sources, such as steam plants.

Manpower Requirements

Manpower requirements for an incinerator system with waste heat recovery are usually greater than for a conventional incinerator. Additional personnel are required to operate and maintain boiler water treating equipment, steam condensing equipment, boiler auxiliary fuel pumps, condensate pumps, etc. The personnel operating the heat recovery equipment must be skilled and, in some instances, licensed.

Economics

The decision to practice heat recovery at a municipal incinerator should be based on a careful study of additional costs incurred and of the monetary return resulting from the sale or use of the recovered heat. The study should also carefully consider whether there is, in fact, a buyer for the waste heat recovered.

The sale of steam requires an incinerator site close to the buyer because of the high cost of distribution and loss of pressure. Steam prices of $0.25 to $0.50 per 1,000 lb, which can be expected, would bring returns of $0.50 to $3.50 per ton of solid waste burned, assuming steam production from 1 to 3.5 lb per lb of solid waste burned.[3]

The generation of electricity from solid waste for sale to power utilities has not often been practiced in the United States mainly because power of the dependability required by the utility companies cannot be produced economically by solid waste incineration.

The price realized from the generated electricity may range up to 10 mills per kilowatt hr (kwhr). Considering variations in available heat and heat recovery process efficiency, the income derived from the sale of electrical power may range from $1.50 to $5.00 per ton of solid waste. These values were calculated using a steam power cycle efficiency of 25 percent that would yield 7,300 kwhr per 100,000 lb of steam, a steam generation rate of 1 to 3.5 lb per lb of solid waste burned, and an electricity value of 10 mills per kwhr.[3]

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CHAPTER X

INSTRUMENTATION AND CONTROLS

Instrumentation is the equipment used to indicate and record physical conditions, such as weight, temperature, position, flow, time, speed, and voltage. Instruments monitor but do not change the conditions of operation. Controls are mechanisms that change conditions of operation, such as a valve that can change flow direction or a switch that can turn on a motor.[1]

Uses of Instrumentation and Controls

Process Controls. Before process conditions can be controlled, manually or automatically, they must be measured with precision and reliability. Through intelligent application of instruments, these process conditions may be measured in a manner that will effectively aid in the control of the incineration process.

Instrumentation for an incineration process is essential because of the variability of the many factors involved in attaining good combustion. As the heat content of the solid waste varies, changes in the combustion process are necessary. Instrumentation indicates these variations so that automatic or manual control adjustments can be made.

Protection of the Environment. Sensing environmental pollutants and adjusting operating conditions to reduce the pollutants to acceptable levels are important applications of instrumentation and controls. Although with present pollution control technology not all environmental pollutants are fully controllable by operational changes, several applications hold promise or have proven their success. For example, the proper use of instruments and controls that maintain a steady, high temperature in the secondary combustion zone ensures that odor-producing organic matter in the gas stream is completely oxidized to innocuous compounds. In addition to air pollution control applications, instruments can serve to sense the pollution loading of waste waters.

Protection of Equipment. Most safety instruments are employed to detect and sound an alarm or to activate a control when equipment is in danger of damage. This is particularly true for detecting undergrate fire, overheating of the furnace, or backfires in the charging chutes.

Overheating of the furnace chambers or hot gas ducting can cause serious damage in a short time. Temperature sensors with audible and visual alarm systems should be employed to signal these dangers. Increasing overfire air, reducing underfire air, and reducing feed rate are control methods used to reduce furnace temperature. Adjustments can be manual, or the heat sensing instruments can activate an automatic control.

Failure of the cooling water supply, resulting from clogged nozzles, pump failure, electrical power failure, or lack of water, can quickly damage the flue gas cleaning system and fans. Automatically activated auxiliary water supply and bypass ducting are desirable control provisions for such emergencies.

Loss of electrical power can cause extensive damage to the plant. Several incinerators have standby auxiliary power supplies with gasoline, diesel, or turbine engines. When power failure occurs, instrumentation activates an automatic cut-in of an auxiliary power system to prevent damage.

Data Collection. Data provided by instrumentation can be used for evaluating incinerator operation and for designing future incinerators. This information frequently aids design engineers in evaluating the effects of design changes and in trying to identify the causes of a malfunctioning incinerator. Data on plant performance should also demonstrate compliance with air pollution control requirements.

Controlling the Incinerator Process

Types of Control Systems. A control "system" must have four basic elements: (1) the standard of desired performance; (2) the sensor (instrument) to determine actual performance; (3) the capability to compare actual versus desired performance (error); and (4) the control device to effect a corrective change. If these elements are integrated into an automatic system that controls the process to a set standard (such as a household thermostat that holds 70 F temperature), a closed loop or automatic feedback control system is formed. If, on the other hand, control is effected by making a change and then observing the result (such as steering a car), the system is an open loop, or manual system.

Present municipal incinerators generally utilize their instrumentation in conjunction with open loop control systems, although there is increasing use of automatic closed-loop control systems for controlling furnace temperatures and furnace draft.[1]

In an open loop control system, the signal from the instrument may be presented to the operator in one of several forms. Perhaps the most informative is a continuously recorded graphic display, which permits the operator to observe the most recent reading as well as the previous reading to determine whether process conditions must be changed. Graphic displays also establish accurate, permanent record for future analysis. Where the operator does not have to draw conclusions or interpret trends in data, a simple indicating meter is sufficient. Alarms or other similar on-off displays are especially useful where the operator is not required to maintain continuous watch over readings or where a certain value must not be exceeded.

A fully instrumented control room or at least a central instrument panel should be provided so that the plant supervisor has, at a glance, an understanding of the facility performance. If the central instrument panel is not near the furnace operating floor, a separate, auxiliary instrument control panel may be needed at each furnace. The readout on instruments should be easy to understand. For instance, to the furnace operator, the volume of overfire and underfire air expressed as a percentage of maximum amount of air that can be supplied is more comprehensible than the volume expressed in cubic feet. For the operator's convenience, the instruments should be grouped on the panel according to function and use. Also, related measurements could be recorded on a single chart, i.e., furnace temperatures, excess air, and possibly smoke density. The degree and sophistication of instrumentation depends upon plant size and economics.

Usually the indicating and recording instrument readouts are grouped on a control panel centrally mounted on the operating floor, with a system of warning lights or bells to summon the operator when corrective action must be taken. A duplicate panel of critical instruments may be placed in the plant superintendent's office for additional surveillance.

Very often recording instruments indicate the conditions that exist over a 24-hr period on a removable paper chart. These records can be very useful in making statistical summaries of operating conditions and in reviewing operating conditions that may correlate with a malfunction.

Types and Application of Instrumentation and Controls

Types of Instruments. The physical parameters and instruments that can be used to assist in the operation of an incinerator include the following.[1]

1. Temperatures

–Optical pyrometers for flame and wall temperatures in the range of 2,200 to 2,500 F

–Shielded thermocouples (Chrome-Alumel) for furnace temperatures in the 1,400 to 1,800 F range, and iron-constantan in duct temperatures down to 100 F Gas- or liquid-filled bulb thermometers for duct temperatures below 1,000 F and for ambient temperatures and water temperatures

2. Draft Pressures

–Manometers and inclined water gauges for accurate readout close to the point of measurement

–Diaphragm-actuated sensors where remote readouts are desired

3. Gas or Liquid Pressures from 1 to 100 psi

–Bourdon-tube pressure gauges for direct readout

–Diaphragm-actuated sensors for remote readout

4. Gas Flows

–Orifice or venturi meters with differential pressures measured by draft gauges

–Pitot tubes and draft gauges

5. Liquid Flows

–Orifices with differential pressure measurement

–Propeller-type dynamic flowmeters

–Weirs

6. Electrical Characteristics

–Voltmeters, ammeters, and wattmeters

7. Smoke Density

–Photoelectric pickup of a light beam across the gas duct

8. Motion

–Tachometers for speeds of fan, stoker, or conveyor drives

–Counters for reciprocating stokers and conveyors

9. Visual Observation

–Vidicon closed-circuit television cameras for viewing furnace interiors, furnace loading operations, or stack effluents

–Peep holes in furnace doors

–Mirror systems

10. Weight

–Motor truck platform scales for measuring the quantity of incoming solid waste and outgoing residue, fly ash, and siftings

–Load cells for automatically weighing crane bucket contents

Application of Instruments and Controls. Temperature measurement is one of the major uses of instrumentation at an incinerator. Temperature should be measured at various locations throughout the furnace and gas passages. These include (1) temperature of incoming air; (2) temperature of gases leaving combustion chamber; (3) temperatures at settling chamber outlet; (4) temperature at cooling chamber outlet; (5) temperature at dust collector inlet and outlet; and (6) stack temperature.

Gas temperature in the furnace are often controlled by increasing or decreasing the amount of underfire and overfire air. The control system can be either manual or automatic. Some automatic control systems not only adjust the amount of overfire air, but also adjust the amount of underfire air needed to maintain a specific ratio with the overfire air.

Underfire air can be controlled so that the flow of air remains constant even though the underfire air pressure varies with the characteristics of the solid waste on the grate. The proper flow and placement of underfire air promotes combustion of solid waste on the grate and reduces the amount of fly ash particulates carried into the gas stream. Total underfire and overfire air flow should be measured and recorded; and the percentage of each to the total flow should also be indicated.

Changes in the amount of overfire and underfire air cause the furnace pressure to vary. To maintain the negative pressure necessary for proper operation, the furnace draft must be controlled. The control can be done manually or automatically by adjusting the speed of the induced draft fan and the chimney draft. Draft pressures should be measured at the following locations: (1) underfire air duct; (2) overfire air duct; (3) stoker compartments; (4) sidewall air duct; (5) sidewall low furnace outlet; (6) dust collector inlet and outlet (pressure differential); and (7) induced draft fan inlet.[2]

The hot exhaust gases leaving the furnace must be cooled to 500 to 700 F to avoid damage to many types of collectors and to the induced draft fan. The gases can be cooled by spraying with water or by dilution with cool outside air. The proper amount of cooling fluids needed can be regulated by a temperature activated control system. A control system should be installed to open an emergency bypass in case the exit gas temperature exceeds a safe limit. This system should also activate an alarm.

Multiple unit cyclone collectors operate best at certain gas velocities. Because of this characteristic, the number of units should vary with the velocity of the gas passing through the furnace. Since the gas velocity is in proportion to the speed of the induced draft fan, fan speed can regulate the number of units needed.

Smoke density can be monitored continuously to check compliance with air pollution requirements. The photoelectric pickup of a light beam across a gas duct can be used to measure particulate density in the exhaust gas. The monitoring device can be ideally located between the particulate collectors and the induced draft fan. The fouling of lenses with smoke is reduced because the negative pressure existing in this area provides good operating conditions for the device.

An incinerator should include the instrumentation necessary for determining the weight of incoming and outgoing material; overfire and underfire air flow rates; selected temperatures and pressures in the furnace, along gas passages, in the particulate collectors, and in the stack; electrical power and water consumption of critical units; and grate speed.

Operational Problems Involving Instruments

Carefully written specifications for instrument type, quality, and location, followed by proper installation and routine testing and preventive maintenance are keys to successful instrument operation. Many instruments need frequent calibration to ensure accurate and reliable readings. Dust can also interfere with the working of the instruments, and the hot and sometimes corrosive flue gas stream can deteriorate the sensing elements inside the gas passage. Although the instrument responds, a testing program is necessary to verify and maintain the accuracy of the readings.

Repair and maintenance of instrumentation often require qualified personnel. Contract services should be used if qualified instrument repair personnel are not available at the incinerator. Incinerator personnel, however, should be trained to identify and correct everyday problems such as clogging of transmission lines, fouling and damaging of sensing devices, and improper charting and inking. A maintenance and repair service contract to correct daily problems is not warranted when the expense and the time lag from reporting the malfunction to its correction are considered.

The incinerator personnel should be trained in the use and interpretation of data received from the instruments. Even if the operators do not use the data directly, knowing its intended use may motivate the operators to obtain an accurate reading.

Future Needs

Improvements in and wider application of instrumentation and controls hold promise for upgrading routine operations and for lowering the operating cost of incinerators. Although the application of present-day instrumentation and control technology can improve the state of the art, new concepts as well as designs and applications in controlling the combustion process are needed. Certainly the need for improvements in measuring and controlling the weight input into the furnace is recognized. An improved device for monitoring smoke and particulate emissions is also needed. Further research is also needed to understand the limitations of instruments, to ascertain the best instrument locations, and to better correlate the instrument readings with incinerator performance.

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CHAPTER XI

INCINERATOR EFFLUENTS AND THEIR CONTROL

Improper design and operation of an incinerator can pollute air, water, and land. Strict air and water pollution legislation at all levels of government, coupled with the trend to locate incinerators close to the sources of solid waste (to reduce hauling cost), requires an overall upgrading of the incinerator process to ensure that it does not adversely affect the environment.

The unit processes associated with incineration (Figure 14) that can cause environmental pollution, except air pollution from stack emissions, are discussed in this chapter. Air pollution control is discussed in Chapter XII.

Odor, Dust, and Litter

Operation of the tipping and storage area can cause dust, litter, and noxious odors. Odor problems from putrefaction of organic materials are especially severe if waste is held in the storage pit for long periods, and several days is not unusual, even in the best managed plants. The dust and odors generated can cause extremely unpleasant working conditions.

Frequent sweeping of the tipping floor effectively controls litter. Washing the floor with cleaning-disinfecting solutions and frequently removing putrescibles from the pit floor aid in the control of odors and insects. Pine oil may also be added to the washing solution as an odor masking agent.

Fenthion, diazinon, naled, dimethoate, ronnel, and malathion are among the effective insecticides for control of flies and other insects. These residual toxicants may be applied directly to the floor and lower portion of the walls of the tipping area and the charging area with a simple, inexpensive garden sprayer. Most of these insecticides are available as bait in granular form that may be sprinkled on the floors. An extensive list of pesticides and instructions for their application has been compiled.[1]

Odor and fly control are facilitated if the storage pit is divided; the separate sections can be alternately emptied and cleaned. Dust and litter can be partially controlled with water sprays that are intermittently used when the dust level is high.

Water used for dust control and for periodic washdown to control insects and rodents is a potential pollutant. Current practice makes no attempt to integrate these waters into in-plant water treatment facilities, but allows drainage to surface waters or sanitary sewers. The pollution is considered minimal compared with that of other process waters. Even so, these waters should be conveyed to an onsite or offsite treatment process.

Many dusty, odorous operations in industry are fully enclosed and internal air is processed through air purification systems. One fully enclosed transfer station is utilizing activated charcoal filters to purify the air.[2] Such innovations may have application to odor and dust control of solid waste tipping, storage, and charging in incineration. In Europe, strategically placing combustion air intakes within an enclosed tipping area has met with some success in controlling dust and odor.

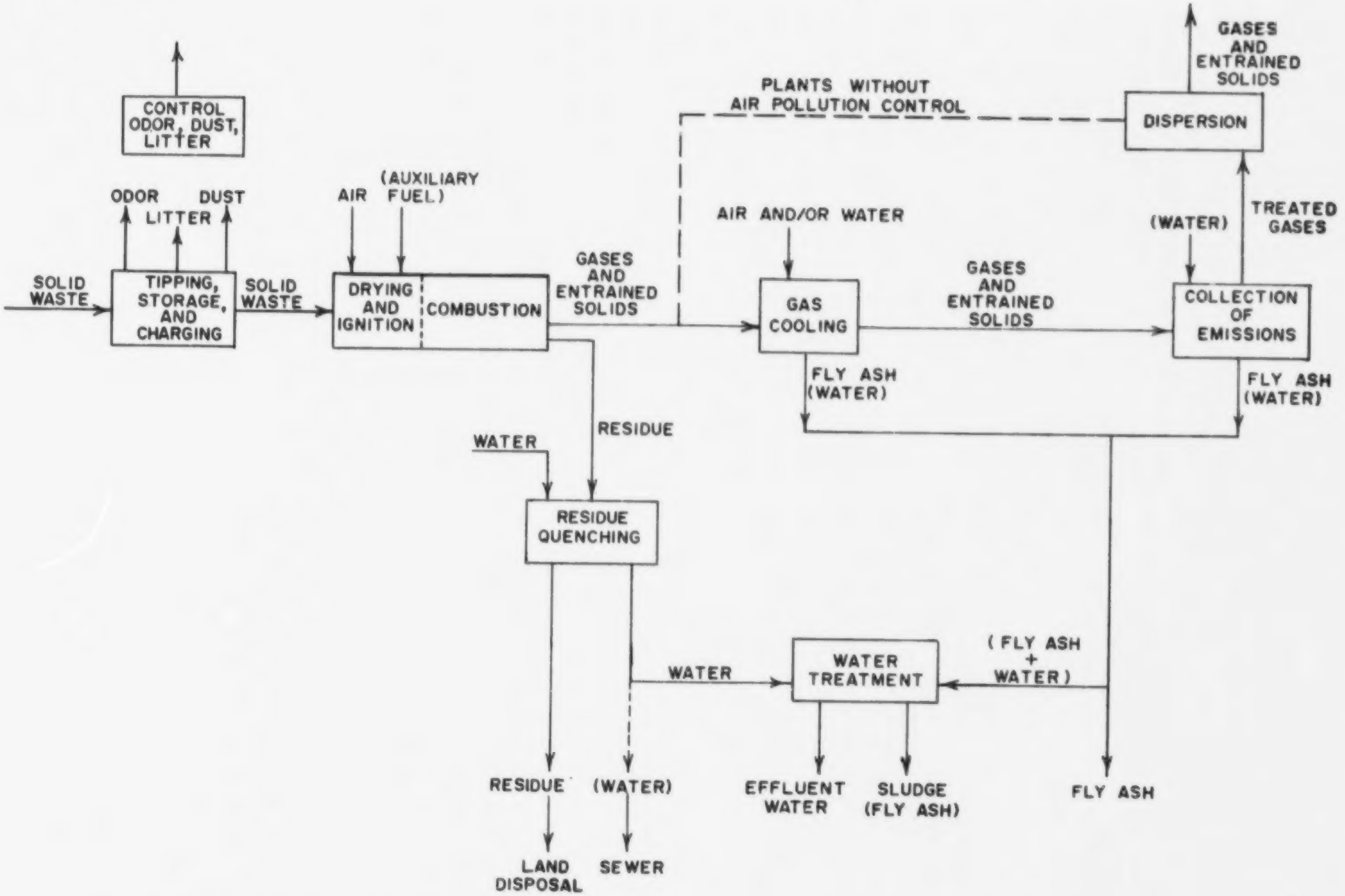

Figure 14. Diagram of the inplant systems based upon dry fly ash collection and conveying from cooling and collection operations. Alternatives for wet collection and conveying shown in parentheses.

Residue from Combustion

Residue consists of all solid materials remaining after burning. It includes ash, clinker, tin cans, glass, rocks, and unburned organic substances. Residue from incineration of municipal solid waste commonly is 20 to 25 percent of the original solid waste. Uncompacted residue occupies 10 to 20 percent of the original volume of solid waste in the pit.

Incinerator residue is permeable and may contain water soluble inorganic and organic compounds. If water moves through the deposit of residue, leaching can occur. Pollution can occur if the leachate water moves through the underlying soil and enters the groundwater. Surface water can also become contaminated where the leachate moves laterally through the surrounding soil and seeps out at ground surface. In many cases, therefore, only sanitary landfill methods can be employed to dispose of incinerator residue.

Where there is no danger of water pollution, residue may be used as a fill material if the residue does not attract insects or rodents.

At the present time, there are no specific and universally accepted quality standards for residue from municipal incineration. Residue containing less than 5 percent combustibles, measured in terms of total dry weight of residue, and having a total volume of less than 10 percent of the original solid waste charged may, however, be acceptable from the standpoint of volume reduction in most locations. The degree of burnout will also affect the degree of protection afforded environmental quality.

The combustible content of residue is not the only true measure of protection of environmental quality. Other tests, still in the developmental stage, must be used to measure the potential of residue to cause odors, attract insects and rodents, and pollute water.[3,4]

Fly Ash

One of the products of incineration is fly ash. This portion of the residue consists of the solid particulate matter carried by the combustion gases. Fly ash includes ash, cinder, mineral dust, and soot, plus charred paper and other partially burned materials. The size of most fly ash particles ranges from 120 to less than 5 microns. Distribution within this range is extremely variable. The inorganic fraction of fly ash is usually the major constituent and consists mostly of oxides of silicon, aluminum, calcium, and iron.

The collected fly ash may be transported in a water slurry or handled in a dry state. Fly ash process water has large amounts of solids and a low pH (Table 7). Because of these characteristics, sluicing water should be treated before final disposal. Usually it can be treated with the residue process water. Dry fly ash, which is difficult to handle, can be easily picked up and scattered by the wind. At the incinerator plant, dry fly ash should be stored in suitable closed containers. If stored in the open, the surface of the ash pile should be kept moist. When transported to the final disposal site, fly ash should be in closed containers unless intermixed at the incinerator with the moist residue.

Fly ash that is open-dumped is a potential source of pollution. Left uncovered, dry ash can create a dust problem and can also be a source of water pollution because the ash contains water soluble compounds. Sanitary landfill methods are often necessary, therefore, to dispose of fly ash.

Process Water

Almost without exception, all incinerator plants utilize water for residue quenching. In addition, many plants use water for wet bottom expansion chambers, for cooling charging chutes, for fly ash sluicing, for

TABLE 7

CHARACTERISTICS OF INCINERATOR WASTE WATER*

Characteristic	Plant 1† Residue quench			Plant 2† Residue quench			Plant 3† Residue Quench			Plant 4† Residue quench			Plant 5† Fly ash effluent			Plant 6† Fly ash affluent		
	Max	*Min*	*Avg*	*Max*	*Min*	*Avg*	*Max*	*Min*	*Avg*	*Max*	*Min*	*Avg*	*Max*	*Min*	*Avg*	*Max*	*Min*	*Avg*
pH	11.6	8.5	10.4	11.7	6.0	10.5	11.8	9.4	11.0	11.8	6.0	10.1	6.5	4.8	5.8	4.7	4.5	4.6
Dissolved solids, mg/l	9.005	597	3,116	7,897	1,341	4,283	7,929	901	3.894	5,993	1,214	2.551	9,364	7,818	8,838	6,089	5,660	5,822
Suspended solids, mg/l	2,680	40	671	1,274	7	372	1,888	72	653	5,476	14	879	398	208	325	2,010	848	1,351
Total solids (% volatile)	53.6	18.5	36.3	51.6	10.5	31.2	47.4	17.8	26.6	57.6	11.3	34.6	–	–	–	24.69	23.26	23.75
Hardness ($CaCO_3$) mg/l	1,574	216	752	1,370	112	889	1,438	574	904	1,462	282	739	2,780	2,440	2,632	3,780	3,100	3,437
Sulfate (SO_4) mg/l	430	110	242	780	115	371	565	115	300	830	125	242	1,350	1,125	1,250	862	625	725
Phosphate (PO_4) mg/l	55.0	0.0	23.3	212.5	1.0	23.5	225	2.5	33.8	127.5	0.5	23.9	15.0	11.5	13.0	76.2	32.2	51.5
Chloride (Cl) mg/l	3,650	50	627	2,420	76	763	1,940	128	868	944	172	393	3,821	3,077	3,543	2,404	2,155	2,297
Alkalinity ($CaCO_3$) mg/l	1,250	215	516	1,180	292	641	1,290	337	682	749	192	465	28	16	23	4	0	1.33
Five-day BOD at 20 C	–	–	–	–	–	–	–	–	–	–	–	–	13.5	6.2	8.8	–	–	–

**Data Sources:*

Plants 1 through 4: SOLID WASTES PROGRAM. Report on the municipal solid wastes incinerator system of the District of Columbia. Cincinnati. U.S. Public Health Service, June 1967. 77p.

Plants 5 and 6: Bureau of Solid Waste Management. Unpublished data (SW-11ts) (SW-12ts). Values were determined from data taken at Ogden, Utah; and Alexandria, Virginia.

†Plant 1, 110 TPD, batch, residue quench only;
Plant 2, 425 TPD, batch, residue quench only;
Plant 3, 500 TPD, batch, residue quench only;
Plant 4, 500 TPD, batch, residue quench only;
Plant 5, 300 TPD, continuous feed–Fly ash effluent only;
Plant 6, 300 TPD, continuous feed–Fly ash effluent only.

residue conveying, and for air pollution control. The quantity of water required depends on plant design, on how well the system is operated, and whether water is recirculated. Jens and Rehm[5] reported total water requirements without recirculation for a 300-ton-per-day plant with two 150-ton continuous feed furnaces to be about 2,000 gal of water per ton of solid waste charged. Quenching and conveying used 1,800 gal and the wetted baffle dust collection system used 200 gal. The study indicated that use of a recirculation, clarification, and neutralizing system reduced the total water needed from 2,020 to 575 gal per ton of solid waste.[5]

Because of extreme variation in incinerator design, generalizing on water requirements is of only limited value. A rule of thumb, however, is that residue quenching and ash conveying at most plants requires 1,000 to 2,000 gal of water per ton of solid waste processed. With water treatment and recirculation, total water consumption can often be reduced 50 to 80 percent.

Studies have shown that incineration process water contains suspended solids, inorganic materials in solution, and organic materials that contribute to biochemical and chemical oxygen demand (Table 7).[6,7] A limited study of incinerator waste waters from a 50-ton-per-day, batch feed incinerator and from a 300-ton-per-day, continuous feed municipal incinerator showed the presence of bacteria in the waste water from both operations.[8]

The studies indicated that incinerator process waters can be contaminated and, therefore, should not be discharged indiscriminately to streams or other open bodies of water.[3-5] The most straightforward control is the discharge of these waters to a sanitary sewer for subsequent handling in a central treatment plant. If the waste process waters cannot be ultimately discharged to a sanitary sewer, the incinerator plant should be equipped with suitable means for primary clarification, pH adjustment, and, if necessary, biological treatment to meet local standards.

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CHAPTER XII

AIR POLLUTION CONTROL

Entrained particulates and some gaseous products are the major air pollutants from the incineration of solid waste. Although not extensive, a number of investigators have identified the quantities and nature of these effluents.[1-4]

Particulate Material

The important properties of the entrained particulate matter, from the standpoint of its collection, are quantities, particle-size distribution, specific gravity, electricity resistivity, and chemical composition.

Quantities. Stenburg and Walker and Schmitz have quantified entrained particulates emitted from refractory furnaces (Figure 15). The data were based upon studies of furnaces ranging in size from 50 to 250 tons per day employing a variety of grate configurations.[1,3] An important parameter that appears to affect furnace particulate emission is the quantity of underfire air utilized in effecting acceptable combustion of solid waste charged. Values from about 10 lb fly ash per ton of solid waste burned to over 60 lb per ton have been reported from combustion of typical municipal solid waste. Adjustment of underfire air may partially control emissions of entrained particulate matter. The data on operating plants indicate, however, that adequate combustion of the solid waste requires substantial quantities of underfire air, so that this technique for reduction of furnace particulate emission cannot be utilized without substantially affecting the capacity of the furnace to burn solid waste.

Particle-Size Distribution and Specific Gravity. These two properties of particulate matter are critical to the performance of most particulate collectors and essentially determine the level of sophistication of air pollution control equipment required to meet a given stack emission objective. Generally, the larger the size and the higher the specific gravity, the easier the particles can be collected. Coarse, high-density materials can be collected in simple inertial devices such as settling chambers and cyclones. Fine, light materials require more sophisticated techniques such as high-energy wet scrubbing.

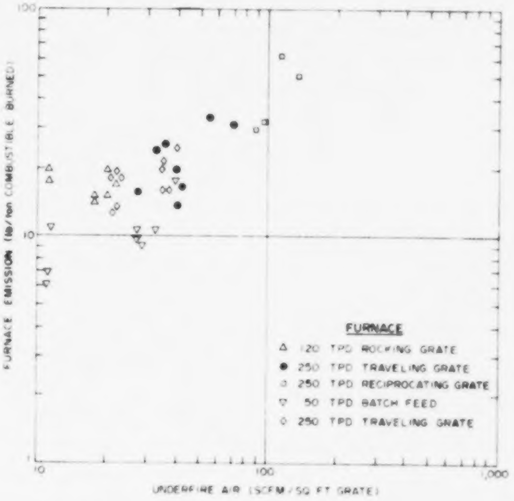

Figure 15. Entrained particulate emissions.

fabric filtration, or electrostatic precipitation. Generally, the percentage, by weight, of fly ash less than 10 microns in diameter determines whether simple or more sophisticated collection techniques are required.

Data on typical particle size distribution, specific gravity, and combustible content of entrained particulates leaving the furnaces of large (125- to 250-TPD) continuous-feed refractory furnace incinerators are shown (Table 8).[3] The values were typical of entrained particulates from three different refractory furnaces with capacities ranging in size from 120 to 250 tons per day and burning typical municipal solid waste. Because the nature of the waste charged and the furnace conditions materially affect particle size distribution, caution must be exercised in generalizing from this information. Nevertheless, if high collection efficiencies are to be obtained, substantial quantities of material in the size range below 10 microns must be collected.

Electrical Resistivity. Electrical resistivity of the fly ash is the property of prime interest when electrostatic precipitators are considered for particulate collection. High resistivity particulates cause disturbances in electrical operation that reduce collection rates. In general collection of particulates with higher resistivities requires larger and more expensive precipitators. Wet scrubbers or fabric filters may be preferred if resistivity is very high. Very low resistivities are also troublesome, but can be handled in properly designed precipitators. When the resistivity is low, the dust readily loses its charge to the collecting electrode and takes on a positive charge. The particle is then repelled by the positively charged collecting electrode; this can cause the particle, particularly if it is large, to reenter the gas stream.

The optimum range for efficient operation of an electrostatic precipitator lies between 10^4 and 10^{10} ohm-cm. Thus, to select the most suitable air pollution equipment, the resistivity of the fly ash must be known. Typical resistivity-temperature curves of entrained particulates leaving large, continuous feed refractory furnace incinerators were charted by Walker (Figure 16).[3]

TABLE 8

PROPERTIES OF PARTICULATES LEAVING FURNACE

Physical analysis	Installation		
	1 (250 TPD)	2 (250 TPD)	3 (120 TPD)
Specific gravity (gm/cc)	2.65	2.70	3.77
Bulk density (lb/cf)	-	30.87	9.4
Loss of ignition at 750 C (%)	18.5	8.15	30.4
Size distribution (% by weight)			
< 2 μ	13.5	14.6	23.5
< 4 μ	16.0	19.2	30.0
< 6 μ	19.0	22.3	33.7
< 8 μ	21.0	24.8	36.3
<10 μ	23.0	26.8	38.1
<15 μ	25.0	31.1	42.1
<20 μ	27.5	34.6	45.0
<30 μ	30.0	40.4	50.0

Gaseous Combustion Products

Kaiser[2] related the quantities of the major gaseous products of combustion leaving the incinerator furnace to the percent excess combustion air when burning typical municipal solid waste (Figure 17). Over 99 percent of the flue gases are carbon dioxide, oxygen, nitrogen, and water vapor, and these are not air pollutants.

Statistical studies on over 40 U.S. refractory furnace incinerators, designed from 1964 to 1966, indicated median design values on total incinerator airflow of 8 to 10 lb per lb solid waste; these values would correspond to values of 175 to 240 percent excess air.[5] Data on combustion air quantities for water tube wall furnaces in the United States are not generally available because of their rare use. European practice with water tube wall furnaces, however, indicates values of 50 to

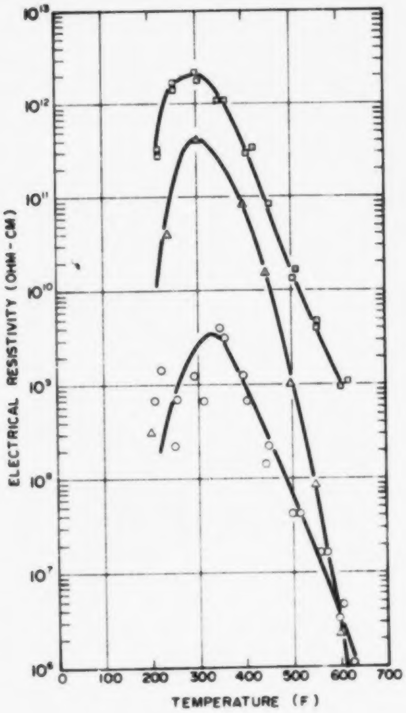

Figure 16. Bulk electrical resistivity of entrained particulates leaving three large, continuous feed furnaces at 6 percent water vapor.

100 percent excess air. The reduced volume of combustion products per ton of solid waste burned that results from lower excess air operation in water-cooled furnaces is an advantage when high efficiency air pollution control equipment is used.

In addition to the major gaseous products of combustion, trace gases present in the effluent can cause air pollution either because of their odor; their direct effect on plants, animals, and property; or their interaction with components of the ambient air to form undesirable secondary compounds. A number of these have been identified (Table 9).[1,4] Compared with other major combustion processes that contribute gaseous pollutants to the atmosphere, such as combustion of fossil fuel, the contribution of gaseous pollutants by incineration of solid waste appears to be low. The sum of the emission of nitrogen oxides and sulfur oxides from large steam-electric generating stations, for example, may be 10 to 100 times higher per ton of fuel than municipal solid waste incineration. The principal exceptions are those trace constituents that can cause odor in incinerator stack effluents. The specific composition and odor threshold concentration of these constituents have not yet been identified.

Water Vapor Plumes. The undesirability of water vapor depends on the importance attributed to the psychological effect of dense, visible water vapor plumes. In rural or industrial locations, the psychological impact of water vapor plumes may be small. In residential locations, the effect may be significant and a critical factor in the overall plant design.

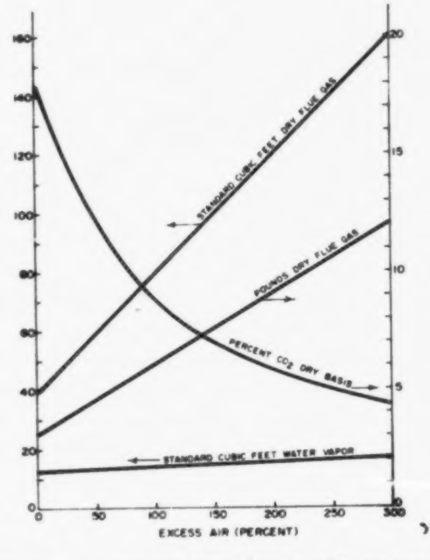

Figure 17. Gross products of combustion per pound of solid waste. 20 percent carbon remaining in total residue. Solid waste composition based on Kaiser's analysis. Standard conditions for measuring gases are 29.92 inches Hg and 70 F at 60 percent relative humidity.

Three general situations are encountered in the treatment of exhaust gas stream: (1) gas cooling to temperatures acceptable to particulate emission control equipment is achieved without vaporization of water, i.e., radiation, dilution, or indirect heat exchange—either gas-to-gas or gas-to-liquid; (2) gas cooling to acceptable temperatures is achieved either partially or totally by vaporization of water, and particulate collection is dry; (3) gas cooling and particulates collection is achieved [illegible] wet methods.

TABLE 9

TRACE GAS CONSTITUENTS IN INCINERATOR EFFLUENT[1,4]

Gaseous emissions (lb/ton)	Typical municipal solid waste*	Mostly branches and twigs (no garbage)
Aldehydes	23.6×10^{-4}	1.1
Sulfur oxides	--	1.9
Hydrocarbons†	0.8	1.4
Organic acids‡	--	0.6
Carbon monoxide	0.51	--
Nitrogen oxide	2.7	2.1
Ammonia	--	0.3

*Typical municipal solid waste: Converted from reported units in pounds per 1,000 lb flue gas at 50 percent excess air to pounds per ton solid waste based on "typical refuse," as established by Kaiser.

†Hydrocarbon expressed as methane.

‡Organic acids expressed as acetic acid.

In situation 1, absolute humidity is low (approximately 0.07 lb water vapor/lb dry gas) since no water vapor is added in cooling. Temperatures of the gases are high (450 to 600 F) so that dispersion capability is good. Because of the low humidity and high temperature, water vapor plume occurrence will probably be restricted to very low ambient temperatures. In situation 2, absolute humidities may be several times higher (approximately 0.25 to 0.30 lb water vapor/lb dry gas) since a substantial amount of water is evaporated in cooling the gases from stack temperatures of 1,200 to 1,800 F down to 450 to 600 F; however, stack temperatures are still high, dispersion capability is good, and condensate plumes will probably be limited to situations of low ambient temperature and intermediate ambient temperatures associated with high relative humidity. In situation 3, particulate scrubbers saturate the gas with moisture, absolute humidities are high (under adiabatic saturation conditions approximately 0.6 lb water/lb dry gas), and effluent temperatures are low (in the range of 175 to 180 F under adiabatic saturation conditions) so that dispersion capability is poor and condensate plumes will occur under almost all atmospheric conditions.

Condensate plumes are usually not harmful, and local complaints may possibly be reduced by proper preeducation and public relations regarding water vapor plumes. On the other hand, there have been complaints of corrosion on automobiles resulting from condensate fallout and of a decrease in visibility at ground level on roadways, etc., that have been connected with water vapor plumes from incineration. Thus, these potential problems must be given serious consideration in the design of the plant.

Desired Emission Levels

Gaseous Emissions. The principal gaseous emissions from incineration are common to all combustion processes: carbon dioxide, water vapor, nitrogen, and oxygen. These are all normal atmospheric constituents, and no control is necessary. In recent years, attention has been directed toward the control of emission of sulfur oxides, nitrogen oxides, carbon monoxide, hydrogen chloride, and total hydrocarbons. With the possible exception of sulfur oxides, no maximum permissible emission levels have been developed, although criteria do exist in certain critical areas on nitrogen oxides and total hydrocarbons. In the specific case of solid waste incineration (excluding open burning), emission of all these gaseous contaminants apparently is well below present or contemplated criteria. Thus, at the present time, and with the exception of the control of those trace emissions that cause odors, the control of other trace gaseous emissions from incineration appears of minor concern.

Gas-Suspended Particulate Emissions. Specific quantitative emission limits on gas-suspended particulates are becoming increasingly prevalent in the air pollution codes of many municipalities and States as well as in the operation of Federal facilities. These codes may be expressed in a variety of ways, such as: (1) total weight of suspended particulate per unit volume of exhaust gases; (2) total weight of suspended particulate per unit weight of exhaust gases; (3) total weight of suspended particulate emitted per unit weight of solid waste charged. Further, to prevent compliance with emission codes by simple dilution of stack gases with air or water vapor, almost all codes require correction of these emission limits to a specific reference condition.

At the present time, the most commonly used units for emission values in incinerator practice are pounds suspended solids per thousand pounds of dry flue gas corrected to 50 percent excess air and grains per standard cubic foot (29.92 in. Hg and 70 F) of dry flue gas corrected to 12 percent carbon dioxide. The reference conditions of 12 percent carbon dioxide and 50 percent excess air are approximately equivalent for municipal solid waste. Figure 18 gives approximate equivalents of the most common units, to 1 gr per standard cu ft of dry gas as sampled, for typical municipal solid waste under various combustion conditions.

Some representative gas suspended particulate emission limits (as they existed in early 1968) have been summarized (Table 10).[2] In the absence of local regulations, the code established by U.S. Department of Health, Education, and Welfare should apply (Appendix B).

Visual Emission Levels. In addition to provisions limiting the quantities of particulate emission, many codes at the municipal and State level also have opacity restrictions—usually based upon the Ringelmann chart.[6] The Ringelmann number is determined by a comparative visual observation of the stack plume and a series of reference grids of black lines on white that, when properly positioned, appear as shades of gray to the observer. Although the quality of a plume in equivalent Ringelmann numbers is not easy to determine, trained observers, properly positioned in relation to stack, sun, and wind direction, can provide satisfactorily consistent evaluations.[7,8] Water vapor plumes complicate observations of stack gases, but again, trained observers can distinguish between water vapor and residual plumes under selected weather conditions.

The trend in most codes on incinerator emissions based on Ringelmann is to require that: (1) normal, continuous plume quality not to exceed Ringelmann No. 1; (2) for short periods not exceeding 3 to 5 min in any one

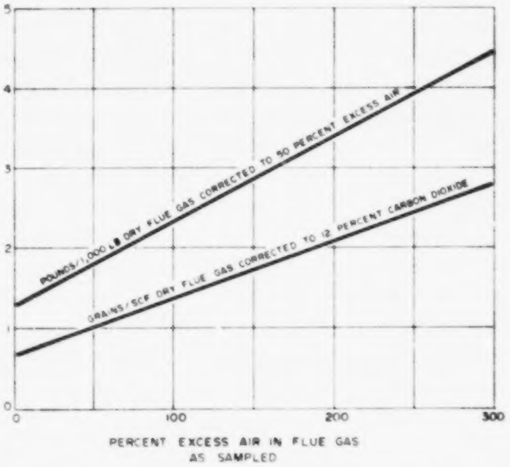

Figure 18. Dust concentration equivalents for 1 gr/SCF (29.92 inches Hg and 70 F) dry gas as sampled, as a function of percent excess air in sampled gas. Conditions are based on Kaiser's typical refuse with 20 percent carbon remaining in the residue. Example: correct 1.5 gr/SCF as sampled at 200 percent excess air to gr/SCF at 12 percent carbon dioxide. From graph: 1 gr/SCF as sampled at 200 percent excess air = 2.1 gr/SCF when corrected to 12 percent carbon dioxide; therefore, 1.5 gr/SCF at 200 percent excess air when corrected to 12 percent carbon dioxide = (1.5)(2.1) = 3.15 gr/SCF.

hour, plume quality not exceed Ringelmann No. 2, and (3) plume quality clearly resulting from water vapor only be excluded from regulation.

Plume opacity refers to the inability of light to pass through the gas plume and is usually applied in cases where the plume is some color other than gray or black. Opacity readings are expressed in terms of percent visibility through the gas plume.

From the standpoint of plant design, a basic problem arises from the fact that the entire technology of particulate collection has been based upon quantitative reduction in the weight of total suspended materials. Thus, to establish the level of control required to meet a given visual code, this code must be expressed in some quantitative gravimetric units. Consistent and general criteria for correlating gas quality measurements, such as Ringelmann number, with quantitative emission in the case of incinerators are not yet available. Therefore, the collection efficiency required to meet a particular Ringelmann number is virtually impossible to predict. Experience with large, coal-fired steam generators indicates that loadings in the range of 0.01 to 0.02 gr per cu ft of exit gas result in stacks optically clear of suspended particulates (i.e., less than Ringelmann No. 1). Achievement of these stack concentrations in coal firing requires collector efficiency in excess of 99 percent by weight. Similarities in particle size distribution from coal-fired steam generators and from incinerators indicate that efficiencies of this order will be required on incinerators if completely clear stack emissions are to be achieved.

Methods of Control

Control of Odors. The best approach to the control of odors generated in the drying and combustion process is maintenance of adequate retention time and sufficient temperature to ensure complete combustion of hydrocarbon vapors to carbon dioxide and water. Elimination of odors from stack gases demands that mixing of any volume of gas containing odors must be completed so that the required excess air and temperature conditions are reached in every stream of gas. A 0.5 sec residence time before the temperature of the mixed gas falls below 1,500 F is generally sufficient. If the temperature at the exit of the furnace is kept above 1,400 F, temperatures within the combustion chamber will be sufficient to eliminate odors.

TABLE 10

TYPICAL PARTICULATE EMISSION CODES FOR COMBUSTION OF SOLID WASTE IN A 250-TON-PER-DAY INCINERATOR BURNING TYPICAL SOLID WASTE

		Approximate equivalent value	
Agency	Emission limit (as written)	lb/1,000 lb dry flue gas corrected to 50% excess air	gr/std dry cu ft corrected to 12% CO_2
U.S. Dept of Health, Education, and Welfare, regulations, for Federal Installations	0.2 gr/std dry cu ft corrected to 12% CO_2	0.36	0.2
Bay Area APCB San Francisco, California Reg. 2, Chapter 1	0.2 gr/std dry cu ft corrected to 6% O_2	0.36	0.2
State of New Jersey (proposed Chapter XI)	0.1 gr/std dry cu ft corrected to 12% CO_2	0.36	0.1

Another odor control technique is to dilute the odorous gas in the atmosphere to a value below its threshold odor so it is unapparent to a receiver. This is achieved through the use of stacks of sufficient effective height. Effective stack height is a function of both the actual stack height and plume rise as the gases leave the stack. The height a plume will rise above the stack is a function of the ambient temperature and the gas temperature, exit velocities of the stack gases, and the stability of the atmosphere. If the threshold value of any identifiable odorous gas is known, methodology is available for estimating the maximum quantitative emission that will keep odorous gas below the threshold value at the nearest receiver. Presently, however, this technique for controlling odors is not being used for two reasons: (1) the ability to eliminate odors by proper process operation; and (2) the absence of identifiable odorous contaminants and their threshold values.

Data on 107 existing batch feed plants indicate a maximum stack height, above grade, of 250 ft, a minimum of 39 ft, and an average of 133 ft.[5] On 44 continuous feed plants, the values were: maximum 250 ft, minimum 25 ft, and an average of 145 ft. The advances that have been made in the use of meteorological methods and data in the design of stacks as pollutant dispersion devices appear applicable to the design of stacks for incinerator plants. This suggests the desirability of competent meteorological consultation to determine stack heights.

Control of Gaseous Emissions from Combustion. Both nitrogen oxide and sulfur oxide emissions occur in solid waste incineration, but the amounts per ton of fuel burned are several orders of magnitude below those involved in the combustion of fossil fuel. Solid waste is inherently a "clean fuel" from the standpoint of sulfur content, with a value of about 0.16 percent by weight[2] as compared to most coals and residual oils used today, which range from about 1 to 3 percent sulfur. Further, there is evidence to suggest that for incineration, most of the sulfur is retained in the ash rather than as oxides in the stack. Thus, sulfur oxide emissions from solid waste incineration generally are well below even the most stringent restrictions present or anticipated.

Restrictions on nitrogen oxide emissions from fossil fuel combustion have not yet been formulated. Nitrogen oxide emissions per ton of fossil fuel are over 10 times greater than those in an incinerator. Therefore, it appears unlikely that this contaminant will be regulated in incinerator plants in the near future.

Some concern has been expressed about emissions of hydrogen chloride (HCl) that might occur as a result of incineration of certain plastics. Hydrogen chloride is toxic to the eyes and respiratory system, and if the amounts released during incineration were great enough, a health problem would exist.

The plastic polyvinyl chloride is found in increasing amounts in municipal solid waste. When it is burned, hydrogen chloride is released, and emissions of 2.7, 2.2, 1.4, and 6.8 lb per ton of solid waste incinerated were measured at four New York incinerators.[9] If hydrogen chloride emissions become a problem, control will be necessary, but since this gas is highly soluble in water, it can probably be effectively removed by water scrubbers.

Control of Suspended Particulate Emission from Combustion. The following is a brief discussion of the various types of particulate collection systems, their performance capabilities based upon objective test data, the state of the art of their development with respect to application to incinerators, and some general indication of their capital cost. Cost data are based upon plants in the range of 150- to 200-ton-per-day rated capacity. The particular type of control system used will depend primarily on the desired level of control, taking into account both quantitative and optical emission criteria, and on the overall cost to own and operate the system.

Types of Collectors. Settling Chambers. The simplest and oldest form of particulate particulate collector is the settling chamber with either a dry or wet bottom. With the exception of a very few plants equipped with some form of sprays or baffle system within the settling chambers, this was the only type of collector used in incineration plants in this country before about 1953 or 1954. Available test data on the settling chamber indicate efficiencies in the range of 10 to 34 percent by weight.[3,10,11] Since 1961 and 1962, the use of settling chambers in their simplest form as the only particulate collection device has become essentially obsolete since they are unacceptable as the principal means of air pollution control.

Wetted Baffle–Spray System. Another form of particulate collection device is the wetted baffle or baffle spray system. These systems usually consist of vertical impingement baffle screens that are wetted with water by flushing sprays or overflow weirs. There may be one or more screens in the collection system. Particulate removal efficiency has been measured over a range of 10 to 53 percent by weight at several different installations.[3,10] Pressure drop is in the range of 0.3 to 0.6 in. of water gauge. Water consumption is in the range of 0.5 to 2.0 gal per min per ton of rated capacity. One installation, which uses a spraying section and secondary baffle section, claims an efficiency of 69.4 percent; pressure drop and other operating data are unavailable.[11]

These wet spray or wet baffle systems have been used on over half of the incinerators installed since 1957. Their installed cost is approximately $0.02 to $0.04 per actual cu ft per min of gas at the collector inlet temperature (1,800 F).

Cyclones and Multiple-Cyclones. Batteries of relatively large diameter (24 to 40 in.) parallel cyclones, with involute or scroll type entry connections, as well as small diameter (9 to 12 in.) multiple tube vane type cyclone collectors have been used in about 20 percent of the incinerator installations built or under construction since 1957. Although there is a substantial amount of test data available on the performance of this type of collector, little has been published. Unpublished data confirm published data that indicate efficiencies in the range of 60 to 65 percent.[11] There is little information on the performance characteristics of the small diameter vane type collectors. Experience in a few installations seems to indicate that plugging of this type collector can be a problem when used downstream of gas cooling systems involving the use of water. Experience with cyclones seems to favor the use of the involute type in tube size above 24 in. Maximum reliable efficiency appears to be in the range of 70 to 80 percent.[12] Pressure drop is in the range of 2.5 to 4.0 in. water gauge.

Installation cost for cyclone collectors, not including such auxiliaries as foundations, supporting steel, flues, and ash removal, is in the range of $0.12 to $0.25 per actual cu ft per min of gas treated.

Wet Scrubbers. Approximately 20 percent of the incinerator plants built or under construction since 1957 have been equipped with wet scrubbers. Wet scrubbers differ in their design and operation from wetted baffle collectors principally in that capture of the entrained particulates is accomplished by direct intimate contact of the particulates with the water itself rather than on water-flushed impaction surfaces. The particulates collide with water droplets to effect capture. The water droplets and impacted particles coalesce into larger droplets (greater than 1,000 microns) that are easily collected in an inertial collector. The water droplets are generally formed by either atomizing the liquid into the gas stream or by allowing the gas stream to tear coarse water droplets into the smaller droplets needed for high efficiencies. With atomizing units, most of the operating energy is expended in pumping the water through the spray nozzles; gas pressure drops are generally low. In units where the gas stream tears the water apart, most of the operating energy is expended in moving the gases through the unit; comparatively little energy is consumed in pumping water. In scrubbers, collection efficiency is primarily related to total energy consumption whether it is energy used to pump liquid or energy used to move gas. Again, published test data are unavailable on this type collector, but analysis of their operating principles and comparison of their known performance on suspended particulates with characteristics similar to those from incineration indicate an efficiency capability in the range of 94 to 96 percent at pressure drops in the range of 5 to 7 in. water gauge.

Water requirements range from about 5 to 15 gal per 1,000 actual cu ft per min of gas treated. Pumping power is based on these figures, although actual makeup water requirements can be much lower where recirculating and clarification systems are utilized. Another characteristic of wet scrubbers is that the gases at the collector outlet will be saturated with water vapor, an important consideration in relation to water vapor plumes from the stack.

Because they operate below the dewpoint of many trace corrosive constituents in incinerator flue gases, wet scrubber systems require corrosion-proof construction. The installed cost for the base collector without auxiliaries such as foundations, water treatment systems, pumps, and piping ductwork is in the range of $0.25 to $1.25 per actual cu ft per min of gas treated.

Electrostatic Precipitators. Electrostatic precipitators operate on the principle of electrically charging the suspended particulates and depositing the charged particles on the surface of a collecting electrode. To remove the particles from the collecting electrode, the collecting surface is vibrated, although water sluicing can be used in certain applications.

The electrical properties of the suspended particles, the moisture content of the gas stream, and the temperature of the gas stream affect precipitation operation. Adding moisture can lower the high resistance of inorganic particles. The tendency of carbon to lose its charge before collection can cause some problems, but these can be overcome. Proper insulation of the precipitator, which eliminates the internal dewpoint condensation, can control corrosion caused by moisture in the gas stream. Temperature of the gases is very important to precipitator operation because the resistivity of entrained particles is extremely temperature dependent. Precipitator operation is best at temperatures between 470 and 520 F.[13]

Electrostatic precipitators have no ability to collect gaseous contaminants except as these gaseous contaminants may be absorbed on the particulates removed.

Electrostatic precipitators have been used in Europe for a number of years in incinerator plants that recover heat. Auxiliary fuels such as coal or oil are used under most operating conditions.[14] Efficiencies in the range of 96 to 99.6 percent have been achieved at pressure drops below 0.5 in. water gauge. Electrical power requirements are in the range of 200 to 400 watts per 1,000 actual cu ft per min of gas treated. Inlet temperatures are usually in the range of 350 to 700 F.

During pilot plant feasibility tests, efficiencies of 89 to 94.4 percent were obtained on suspended particulate removal from a 220-ton-per-day continuous feed furnace.[15] Electrostatic precipitators have not yet been operated on a full scale basis in the United States, but several new plants under construction will utilize electrostatic precipitators with design efficiencies in the 90 to 98.5 percent range. The basic advantage of the electrostatic precipitator over other particulate collectors is its high efficiency at low operation cost (pressure drop and electrical power input) and its ability to achieve these efficiencies in a dry system without creating potential water pollution problems. Typical installed cost for electrostatic precipitators, not including auxiliaries such as foundations, supporting steel, flues, and fly ash removal, is in the range of $0.85 to $1.45 per actual cu ft per min of gas treated.

Fabric Filters. Except for a single pilot installation on one municipal incinerator, fabric filters have not yet been applied to incinerators. Although they are used by many industries, their use at incinerators must be considered experimental.

Fabric filters literally filter the suspended particulates from gases in a manner similar to the operation of a vacuum cleaner. The predominant filtering media is the dust cake itself, which accounts for the high efficiencies obtainable (usually in the 99.9% + range).[12] The dust cake, once it has been formed, essentially filters all particles as the gases pass through the pore openings in the cake; these openings are no bigger than the smallest particle in the gas stream.

Their utilization for a given application is almost always based on consideration of temperature, moisture content of the gas stream, pressure drop characteristics of available filtration media, and the service life of these filter media. Fabrics, such as fiberglass and high-temperature synthetics, are available with continuous operating temperature capability up to about 550 F. Many varieties exist, and their costs differ principally in relation to their temperature capability and resistance to chemical attack. Another consideration in the selection of fabric filters is the porosity of the filter cake that is built up on the fabric surface during normal operation. Cake porosity depends on moisture, particle size distribution, and physical and chemical characteristics of the entrained particulates. The typical operating pressure drop for fabric filters would be in the range of 4 to 7 in. water gauge. Initial cost of fabric filters that might be applied to incinerator operations, based upon the use of treated fiberglass bags, would be in the range of $0.75 to $1.50 per actual cu ft per min of gas treated.

Factors in the Selection of Particulate Collectors. Matching the type of collection equipment needed to meet a particular air pollution control objective is illustrated (Tables 11 and 12).

TABLE 11

COLLECTION EFFICIENCY REQUIRED TO MEET VARIOUS EMISSION LIMITATIONS*

Code requirement (lb particulate/1,000 lb flue gas)	Approximate % efficiency* to meet code
0.85#/1,000# @ 50% excess air	74
0.65#/1,000# @ 50% excess air	80
0.20#/1,000# @ 50% excess air	94

*Based on 32 lb of fly ash per ton of solid waste charged entering the collector.

TABLE 12

MAXIMUM DEMONSTRATED CAPABILITY OF VARIOUS COLLECTORS

Type of Collector	Maximum demonstrated efficiency (%)
Settling chambers	34
Wetted baffles	53
Cyclone collectors	70–80
Direct impaction scrubbers (wet scrubbers)	94–96
Electrostatic precipitators	99
Bag filters	99+

Unless furnace operation is to be significantly restricted, particularly with respect to underfire air, even the most lenient quantitative emission code cannot be met with settling chambers or wetted baffles, either alone or in combination. Cyclone collectors can meet 0.85 lb per 1,000 lb at 50 percent excess air and probably can meet intermediate codes. When codes require emissions below 0.65 lb per 1,000 lb at 50 percent excess air; the only demonstrated alternatives are direct impaction scrubbers, electrostatic precipitators, or bag filters.

Control of Water Vapor Plumes. Water vapor plumes may not be directly harmful and are, in most cases, excluded from opacity regulations. Droplet fallout or visible vapor plumes, however, may constitute an important nuisance factor. Usually the plume problem is associated with high efficiency wet scrubbers, so the first method of controlling condensate plume is to use dry gas cooling and collecting techniques. If other factors dictate the use of high-efficiency scrubbers, two alternatives are possible: (1) extract heat from the hot furnace gases *before* collection and reintroduce the extracted heat *after* collection as stack gas reheat. Such a scheme, which involves the use of gas-to-gas heat exchangers, reduces both absolute and relative humidity of the stack gases and improves their dispersion capability at the same time (such systems have been used on incinerators); (2) dehumidify the saturated flue gases by subcooling below the normal scrubber outlet temperatures. Cooling requires the use of a packed cooling tower and a source of cooling water below the wet scrubber exhaust gas temperature. Dehumidification of the stack gases can be achieved by this method, water can be recovered and recycled, and the operating horsepower of high pressure drop fans can be reduced. Dehumidification systems have been used with success in other applications, but have not, as yet, been utilized on incinerators.

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CHAPTER XIII

ACCEPTANCE EVALUATION

Acceptance evaluation is an appraisal of an incinerator (that can be formed) based on inspection and tests during construction and again at the completion of the project. The primary purpose of this evaluation is the determination that all provisions of the contract are being met and that the incinerator performance meets the specifications. The method or means of making the acceptance evaluation are provided for in the terms of the contract.

Construction materials and workmanship are inspected and evaluated from beginning of construction through completion. Individual mechanical components of the system such as fans, grates, valves, etc., are certified by the manufacturer but should also be inspected and checked on the job. The performance of the incinerator, however, cannot be evaluated until all components of the system are assembled within the completed structure, at which time a performance or operational test is conducted. Tests are commonly run simultaneously on all components of the incinerator system.

Many municipal incinerators now in operation were built as a "package deal." The incinerator contractor supplied design, equipment, and facility construction, to produce an end result of "system performance" specifically detailed by the owner. The contractor was responsible for all phases of design, component selection, assembly, construction, and final performance. Because incinerators are now more complex, the current trend is to employ services of a consulting engineer to design the incinerator system to meet the owner's requirements. In this case, the consultant specifies each component and how each is related to the other. The contractor, then, is responsible for construction and assembly of equipment and components in accord with the details of the designer's plans and specifications and may not be required or expected to ensure that the incinerator will meet performance type requirements; this is the responsibility of the design consultant. In the absence of an expressed guarantee by the contractor that the finished job will perform as specified, all the contractor is responsible for is that he has complied with the plans and specifications prepared by the consultant. If unsatisfactory performance is a matter of negligent design, the consultant can be held responsible.

Whether the incinerator is built by "consulting design" or as a "package deal," evaluation must be conducted throughout construction. Defective construction materials and faulty construction methods must be uncovered and corrected at this stage because often corrections cannot be made later. Even where corrections are possible after construction is completed, they are always expensive. Therefore, the owner should obtain the services of a contractor who has demonstrated his capabilities. Both the contractor and the design consultant are responsible for acts of negligence.

Equipment selection is often determined by the manufacturer's willingness to guarantee and accept responsibility for equipment performance. Manufacturers, however, seldom make blanket guarantees. In air pollution control, for example, a manufacturer will not state that his equipment will produce a visually clear stack effluent. He will, however, usually be willing to guarantee that his equipment will remove a fixed percentage of particulates based on standard tests. This distinction should be considered in writing specifications.

Before performance specifications become part of the bid proposal, they should be reviewed by the community's engineering staff to determine that the specified performance will meet the antipollution and other requirements of the community. Legal aspects of the contract should be reviewed with particular emphasis on the responsibilities and liabilities of all parties involved.

A "shakedown period" between completion of the incinerator and final acceptance testing or evaluation is usually required. This period commonly ranges from 30 to 90 days. Since there may be a lag period between completion and acceptance, the effective date of mechanical equipment warrantees should be agreed upon and included in the contract.

The incinerator designer and plant personnel commonly participate in the acceptance evaluation test. The acceptance test should be conducted under the range of conditions expected to occur during normal operation. In the acceptance evaluation of a "package deal," it is advisable to bring in an unbiased third party to determine contract compliance.

The acceptance procedure varies with the community. Usually a community does not take over operation until the plant is accepted; however, the community should have personnel present for training. If the acceptance test fails, a specified time should be given to rectify the situation before penalities or liquidation damages are applied.

Today, there are no consistent performance tests to be used for municipal incinerator acceptance procedure. The methodology for performing various tests, such as stack sampling for particulates and determining residue and effluent water characteristics, have not been standardized. To meet this need, the American Society of Mechanical Engineers and the Bureau of Solid Waste Management are currently developing tests and procedures for evaluating incinerators.

CHAPTER XIV

SOLID WASTES THAT REQUIRE SPECIAL CONSIDERATION

Solid waste may contain combustible items such as discarded furniture, mattresses, automobile and truck tires, tree stumps, logs and large branches, demolition lumber, and industrial boxes, crates, and skids. Solid waste may also contain a variety of noncombustible items such as stoves, refrigerators, water heater tanks, and metal furniture. These items are classified as "bulky solid waste." Because they are too large, would not burn sufficiently in the normal process time, or might damage or interfere with the incinerator mechanism, it is impractical and often impossible to process bulky combustible wastes at conventional municipal incinerators. Municipal solid waste also contains materials that in their collection and disposal may be potentially injurious and therefore deserve special consideration. These are classified as "hazardous wastes" and include radioactive materials, toxic chemicals, and highly flammable or explosive materials. Other municipal wastes that require special consideration include obnoxious substances, such as pathological wastes, and various sludges.

Bulky Solid Waste

Some municipalities dispose of their bulky waste by sanitary land-filling; some practice open burning of the combustible bulky items. Where long haul distance is involved or where land is scarce, land disposal of bulky waste can be quite expensive. Because it is potentially dangerous and causes air pollution, open burning is a poor solution. Some communities have evaded the problem by refusing to collect bulky items. This approach results in illicit dumping or open burning.

Special Incinerators for Bulky Waste

Several cities are now using special incinerators for oversized burnable waste.[1] The incinerators are refractory lined and have a refractory hearth. Charging is by the batch method and burning time is varied to suit the materials. Auxiliary fuel has been used to ignite the solid waste, and in some cases, to ensure complete combustion; however, the bulky waste usually burns readily without the assistance of auxiliary fuel. Charge size is limited by furnace dimension and maximum size of any object is controlled by the dimensions of the door opening.

Size Reduction of Bulky Solid Waste

Preparation of combustible bulky items for burning in a conventional incinerator requires reduction to fragments that can be easily handled mechanically and that will be burned in the normal process time. Equipment used for size reduction has included shears, impact mills, hammermills, flailmills, and chipping devices such as the "wood hog."

Because of the wide variety of items that constitute bulky solid waste and the heterogeneity of materials making up individual items, size reduction has been of only limited success. Some impact mills, hammermills, and chippers are capable of processing presplit logs and presplit stumps, wood pallets and crates, demolition lumber, and large wood furniture to suitable size for burning. Generally, this equipment has not been satisfactory in reducing heavy metal-framed burnable furniture and mattresses containing heavy steel framing and springs. Some shearing equipment can reduce bulky waste containing steel, such as innerspring mattresses, to fragments of size suitable for acceptable burnout when these fragments are intermixed with other solid waste. The noncombustible portion of the processed material does not interfere with incinerator mechanism.

Although the capability of size reduction equipment for bulky solid waste has been demonstrated, the practicality of some of these methods has not been established. An exception is shredding equipment for tree branches; this equipment has been successfully used for years.

The operation of most heavy equipment used for size reduction is extremely noisy and dusty. Heavy, fast-moving parts are inherent to most of the processes. Where such equipment is used, extreme care must be taken to provide for the worker's safety. Most operations require dust control and noise insulation.

Hazardous Wastes

Hazardous wastes are those that are potentially injurious such as highly flammable or explosive materials, toxic chemicals, and radioactive materials. Many hazardous wastes can be routinely handled in small quantities at the incinerator without creating problems. For example, when a half-full gallon-can of volatile paint is heated in an incinerator, the only result would probably be the lid blowing off. The burning of the small quantity of released paint would create no problems. However, a 5-gal drum of volatile paint or other flammable liquid could cause considerable damage to the furnace and could injure the workers. Pressurized cans, so common today, generally cause no damage to the furnace when they "pop." They can, however, be dangerous to workmen when metal fragments are blown through furnace openings. Other hazardous wastes include gasoline, kerosene, oil, and other flammable liquids; sawdust and wood shavings; flammable plastics, especially when finely divided; rubber dust; and flour and magnesium shavings.

Because it would be practically impossible to prevent all hazardous materials from entering the incinerator, precaution must be taken to minimize danger. Large quantities of hazardous wastes can be avoided by prohibiting those generated by industry or by making special provisions for them if they are accepted. A safer, and often more economical, method is to establish a partnership between industry and local government for central disposal of industrial wastes.

Even where hazardous industrial wastes are prohibited, municipal incinerators will occasionally receive dangerous materials from the residential community. The waste collectors will often be in the best position to detect possible hazardous wastes and alert the incinerator personnel. If suspected hazardous wastes are inadvertently dumped into the pit, they must be removed or mixed with the contents of the storage pit until they are at a safe concentration.

A municipal incinerator should not accept radioactive wastes. The handling and disposal of all radioactive wastes must be carried out in accordance with recognized standards and procedures outlined by the Atomic Energy Commission or other responsible agency.

Obnoxious Wastes

Obnoxious wastes are those that are so highly objectionable and unpleasant from the standpoint of appearance, health effects, or odor that they should not be handled in the conventional municipal incinerator without special provisions. Certain wastes generated by hospitals and medical laboratories can be obnoxious and dangerous (disease bearing). These include anatomical wastes, surgical dressings, sputum cups, stool specimens, and other test specimens. Most hospitals dispose of these wastes in pathological incinerators.

Slaughterhouses, butcher shops, and other food processing plants generate quantities of obnoxious wastes that have a high moisture content, are highly putrescible, and may contain pathogens. Most slaughterhouses dispose of their wastes by special drying equipment and incineration. In many large cities, wastes from slaughterhouses and butcher shops are collected by private agencies for rendering and reduction for the production of fats, glycerine, detergents, etc. Dead farm animals and domestic animals may also be collected for this purpose.

With the exception of small birds and mice, dead animals are too large and dense to be consumed in the conventional municipal incinerator process. Some cities have special batch-fed incinerators for burning dead animals and obnoxious substances, including hospital wastes. At some incinerators, refrigerators are provided for storing dead animals for periodic cremation. Some incinerators have access to a hearth in the secondary combustion zone where the animals can be placed until cremated by the hot gases and flame.

Combined Sewage Sludge–Solid Waste Incineration

Like municipal solid waste, the amount of sewage in this country is increasing each year. The cost of ultimate disposal of sewage sludge and associated wastes is increasing as land becomes less available. Sludge incineration has been practiced for many years for volume reduction.

A method of disposal still under investigation is the combined incineration of intermixed sewage sludge, screenings, greases, and scums with municipal solid waste. Some cities in the United States have used combined solid waste-sewage sludge incineration methods.[2] The potential cost savings is based primarily on using the excess heat generated from burning the solid waste to dry the partially dewatered sludge and thus allow it to burn readily. Other potential savings result from the use of a single facility instead of separate incinerators. Although the combined incineration process appears economical, three factors must be considered: (1) hauling costs; (2) sewage sludge moisture; (3) waste production rates that affect uniform blending of the two materials, each of which is variable in itself.

Conclusions

There are obviously many more wastes that require special considerations by the incinerator designer and operators. The engineer must vary his design according to the wastes that may be handled over the life of the plant. To do this, he must have accurate information on the quantity and composition of the wastes. Incinerator design and operation will become increasingly more complex and challenging as communities strive for the single method or single system capable of handling all wastes.

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CHAPTER XV

SALVAGE

Salvage is the recovery of waste goods. Since most of our solid waste contain materials of value, waste disposal officials should consider salvage of waste materials. Many municipalities have practiced salvage. Some of these operations have been profitable; others have become inefficient and a nuisance. Thus, the decision to use salvage and reclamation should be based on a thorough engineering cost and marketing study. In no case should such an operation seriously interfere with the major objective of solid waste disposal.

The major materials occurring in municipal solid waste that may be of value in a salvage operation include ferrous and nonferrous metals, paper, rags, glass, rubber, plastics, and food waste. If all of the materials of value were recovered, the process or operation would be classified as "total salvage." Total salvage has been practiced in the United States, but generally, it has not been successful. In many cases, "partial salvage" has met with variable degrees of success and is currently being practiced. Partial salvage is the selective recovery from solid waste of one or more constituents that have economic value. In connection with incineration, the most commonly salvaged material is ferrous metal.

Total salvage in the United States has failed because it has been uneconomical. The market value of salvage materials has fluctuated severely and some fractions have lost their value completely. The makeup of incoming solid waste is also subject to extreme variation. Materials of value tend to disappear from refuse when the market is attractive. Schools and charitable organizations conduct drives to collect newspapers and magazines or scrap metal. Where permitted, private collectors and scavengers collect metal, rags, and paper for resale. Conversely, when the market price is low, the municipality will be responsible for collection and disposal of larger amounts of paper.

Total salvage is a costly operation. Because of the heterogeneity of solid waste, the process requires a great amount of hand labor. Labor costs have continuously increased whereas, generally, the overall market value of salvaged material has declined. Mechanization and semiautomation techniques in total salvage have not reduced labor cost sufficiently to justify the process.

Municipal officials are hesitant about investing tax monies in projects as uncertain as total salvage. Also, because many salvage operations have been unsightly and have resulted in public health problems, the public is also apprehensive of proposed salvage operations. In spite of these uncertainties and the poor record of past performances, salvage deserves further attention. Theoretically, it is an ideal solution to the solid waste problem and allows conservation of natural resources.

Partial salvage has been conducted either before or after incineration. Rising labor costs, declining salvage market, and variation in solid waste composition have affected partial salvage in much the same way as total salvage.

Removal of some constituents before incineration may affect the combustion process. An increasingly large portion of municipal solid waste is paper, which provides most of the combustibles at an incinerator. Thus, removing paper would lower the heat value of solid waste and the furnace would have to be designed accordingly. An incinerator designed to handle only nonsalvageable materials would be inadequate to handle all solid waste when the salvage market fell too low to justify salvage operations. Similarly, an incinerator capable of handling all solid waste would be inefficiently utilized when a high proportion of the constituents are removed. Noncombustibles such as cans and bottles are believed to aid the incinerator combustion process by creating voids in the fuel bed, thus providing for more uniform burning. Removing these items before incineration might decrease the burning rate.

Salvage of metal after incineration has been successfully conducted at some incinerators. A major advantage of this method is that the volume of material to be processed has been reduced considerably. Other advantages are that the after-incineration process is esthetically more acceptable; the burning process removes much of the undesirable combustible material from the salvage; the primary disposal process, incineration, is not dependent on salvage; and failure of salvage equipment or failure of the salvage market will not directly affect the incineration process for the salvage operation could be bypassed and all residue could be disposed of without making major changes in the operation.

Including a salvage operation with incineration can reduce residue volume and salvage may provide an economic return. The success of salvage depends on the size of the operation, the type of incineration, salvage plant design and operation, the market for salvaged materials, and the shipping cost to the point of usage.

CHAPTER XVI

OPERATION AND MAINTENANCE

Management and Personnel

As a community plans and builds an incinerator, it should also plan for the management and personnel necessary to operate it. The plant supervisor should be employed several months before construction is completed so that he can become thoroughly familiar with each major incinerator component as it is installed. Operating personnel should be obtained early enough so that they can work closely with representatives of the manufacturers and contractors when the incinerator is in the latter stages of construction and put through the acceptance tests. In this way, the incinerator personnel can be trained in proper operation, maintenance, and repair.

At the outset the management, and this includes the plant superintendent, should develop a table of organization showing the number of shifts, number and types of personnel per shift, and standby and maintenance personnel. Several methods of job classification exist; whatever method is used should have sufficient flexibility so that incinerator personnel can be used for various jobs. Rigid job titles that tend to limit operating personnel duties should be avoided.

Staffing needs vary with the size and type of incinerator, number of shifts, organized labor regulations (including working hours, vacations, fringe benefits), and the extent of plant subsidiary operations, such as heat recovery and salvage. The total man-hours required in efficient operation range from 0.5 to 0.75 per ton of solid waste processed. This does not include man-hours for residue disposal and major repair work.

Management needs to provide sufficient employment incentives. An acceptable working environment, equitable pay, advancement, opportunities and training, retirement and other fringe benefits, and employment security are essential.

Operation Guides

Flow Diagram. Every plant should post a scaled engineering drawing, pictorial drawing, or scale model of the plant, showing all major components by name and function. This diagram or scale model should illustrate how the solid waste and its resulting gases and residues pass through the plant, so that plant personnel and visitors may readily understand the various components and how they function together.

Drawings. The local solid waste disposal operating agency should have copies of all engineering drawings, showing the plant and all its components. At least one set of formal drawings should be maintained at the plant for reference by operational and maintenance personnel.

Operation and Maintenance Manuals; Equipment Manuals. Equipment manuals, catalogs, and spare parts lists should be kept at the incinerator for quick reference by employees. A manual describing the various tasks that must be performed during a typical shift and the safety precautions and procedures for working in various areas of the plant should also be kept on hand.

Performance Records

Criteria that may be used for evaluating incinerator operation are residue characteristics (physical and chemical), volume and weight reduction of original solid waste, amount of pollutants released to the environment, various operating costs per ton of solid waste processed, and efficiency of heat recovery equipment or other subsidiary operations. The use of these criteria require that the following data be recorded.

Incoming Solid Waste. Plant records should indicate the total weight of solid waste received during each shift as well as the number of vehicles arriving, identity of vehicles, and the source and nature of solid waste received.

Furnace-Burning Rate, Temperature, and Air Flow Rates. Furnace operators should record furnace temperature at frequent intervals unless such data is recorded automatically. Explanations should be provided for prolonged temperatures above 1,800 F or below 1,200 F. Grate speeds (or rate of operation) should be noted throughout the shift. Air volumes and distribution should also be reported. All readings should be made at least hourly and any major changes noted. Some instruments give indirect readings (draft in inches of water, grate function in amperes, etc.), and so such data must be interpreted in terms of settings required for good furnace operation.

Residue. Operators should record the time or rate of residue removal. Residue should be weighed on the scale as it leaves the plant, and the amount removed should be recorded. Moisture correction is necessary for proper interpretation of residue weight. The dry weight of residue can be estimated by periodically obtaining the average moisture content. Residue quality should be visually determined and recorded.

Water Consumption. Water used for quenching and for scrubbers should be recorded from meter readings or by other means at least at the start and end of each shift.

Power Consumption and Generation. Electricity may be metered at major units to pinpoint those equipment malfunctions that are manifested by changes in power consumption. Power for electrostatic precipitators and large electrical motors should be separately metered. If power is generated, generator records should be kept.

Steam Generation. If steam is generated, flow meters should be installed to record production. Hours of operation at specified rates may be used, as well.

Stack Discharges. Records of stack discharge characteristics commonly include smoke indicator readings, Ringelmann readings, and analyses from stack samplings for particulate emission.

Personnel Records. Accurate personnel time and cost records should be kept so that incinerator performance can be evaluated on the basis of operating cost per ton and on the basis of man-hours per ton. The direct and indirect costs should be added to the total cost of incinerator operation.

Supplies, Material, and Equipment. All supplies, material, and equipment utilized in incinerator operation and maintenance should be recorded and charged against the incinerator, even though provisions or purchases may be made by another department. Major incinerator maintenance (such as rebuilding of refractories), whether done by contract or by plant personnel, should be recorded as cost items separate from incinerator operation. Thus, both the cost of repairs and maintenance and the cost of plant operation can be determined.

Utilization of Recorded Data

Recorded data provide a permanent means of evaluating incinerator performance. This evaluation is needed to guide the day-to-day operation and can also be used for making important adjustments in equipment, operating procedures, and personnel assignments, and periodic reports to the local government.

Maintenance and Repairs

Records. A records system should be established by the plant supervisor wherein periodic maintenance of each incinerator component is scheduled to be done by specific personnel. In contrast, certain maintenance, such as cleaning, lubrication, and adjustment of equipment, may be done by operating personnel as part of their daily or weekly tasks and need not be recorded. Certification that maintenance has been performed should also be recorded. Card files set up with an automatic reminder procedure will provide a permanent record of maintenance for each item of equipment and guard against omission of scheduled maintenance. Properly certified maintenance records, tabs, or seals, may also be affixed to the equipment as maintenance is performed. Major repairs, such as the replacement of refractories, will necessarily be recorded separately. Unscheduled repairs and breakdowns should be handled promptly and carefully recorded so that the cause can be determined and corrected.

Inspection and Repairs. Components subject to rapid wear or damage should be inspected weekly at a time when such components are not being operated. At each inspection, a thorough report should be made, including condition of furnace, repairs performed, and expectation of future repairs or major overhaul. Plant performance records and maintenance files can be used to determine when major repairs are necessary.

When major overhauls are being made, the units remaining in service should not be overloaded to make up for the loss of capacity. The amount of solid waste equivalent to the "down" unit's capacity should be diverted to an approved disposal site or to other incinerators. Ideally, extensive repairs should be scheduled during the season when waste generation is lowest.

Plant personnel will not normally be expected to perform major repairs on equipment, building, or facilities. Other municipal personnel may perform some repairs, and certain repairs will require special contract services.

When general wear and tear accumulates to the point that continued operation is no longer economically feasible or prudent without major reconstruction, the abandonment or demolition of the facility must be considered. Good management demands that such determination be made in time to arrange for the necessary financing and construction of new facilities. Since this process may take several years, adequate lead time is essential. A capable plant operator will be able to aid in this decision.

Management should keep abreast with new development and decide whether the incinerator operation can be improved. The costs of revisions, expected life of the plant, temporary disposal alternatives, and financial considerations enter into these decisions. Unfortunately, the updating of incinerators by redesign and reconstruction has been the exception rather than the rule.

In many instances, incinerators are built with provisions for future enlargement or for later addition of equipment. Here again, performance evaluation will guide the decisions of when to modify equipment or to enlarge capacity.

Maintenance of Buildings. Although certain parts of a plant are inherently dirty, dusty, or difficult to keep clean, devices to reduce accumulation of dust and dirt, water, or debris should be installed, and personnel should spend some time during the shift to maintaining a clean workspace. Misuse of employee facilities, such as accumulating salvage items should not be permitted. In some instances, poor housekeeping creates fire or safety hazards. Lighting fixtures and bulbs should be kept clean to provide acceptable illumination at all times. Auxiliary lighting equipment should be maintained for inspection purposes and for use in emergencies.

Maintenance and Repair Costs. The cost of proper maintenance and repairs varies with the size, type, and age of the plant but can be expected to run between 5 and 10 percent of the total cost of operation, split about equally between labor and materials. Good management will budget for annual maintenance and repair work, including periodic major replacements and modernization.[2]

REFERENCES

1. ROGUS, C. A. European developments in refuse incineration. *Public Works*, 97(5):113-117, May 1966.
2. ROGUS, C. A. Incinerator design. Municipal solid waste disposal. Part 3. *American City*, 77(4):104-106, Apr. 1962. Part 4. *American City*, 77(5):106-108, May 1962.

APPENDIX A

AN ACCOUNTING SYSTEM

for incinerator operations

Eric R. Zausner*

Effective solid waste management requires an adequate information system including data on activity and the costs of operation and ownership. Although a cost accounting system represents only one part of the total system, it does facilitate the collection and later utilization of the data obtained.

Present information on incineration and its associated costs is both inadequate and nonstandardized. The proposed system provides a guide to the type and quantity of information to be collected, its classification, and the method of collection. Incinerator supervisors and heads of agencies responsible for their operations will find the system useful.

A cost accounting system can aid a community in controlling the costs and performance of its incinerator operations, as well as aid in formulating future plans.

Chief, Management Sciences Section, Operational Analysis Branch, Division of Technical Operations, Bureau of Solid Waste Management.

System Benefits

Some of the more important advantages are:

1. The system facilitates orderly and efficient collection and transmission of all relevant data. In fact, most of the data recorded is probably being collected already, although perhaps only sporadically and inefficiently. Hence, the added cost of installing the proposed system is minimal.
2. Reports are clear and concise and present only that amount of data required for effective control and analysis. They can easily be completed and understood by incinerator personnel.
3. Interpretation of results and comparison with data from previous years or from other communities is simplified. This allows analysis of relative performance and indicates areas where corrective action is needed.
4. The system accounts for **all** relevant costs of operation.
5. Because the system indicates high costs and their underlying causes, the supervisor can control costs more effectively. Similarly, performance and efficiency may be monitored and controlled.
6. Accountability is superimposed on the system to indicate who is responsible for the increased costs.
7. The data provided are in a form that aids in short- and long-range forecasting of operating and capital budgets. Future requirements of equipment, manpower, cash, etc., can be estimated to aid budgeting and planning at all levels of municipal goverment.
8. The system, with only minor modifications, is flexible enough to meet the varying requirements of incinerators of different sizes.

Cost Centers and Cost Allocations

The complexity of incinerator operations requires a breakdown and description of operations to facilitate analysis. In this report, the incinerator is assumed to consist of several interrelated suboperations, each of which is analyzed separately. These suboperations are called cost centers because costs are accumulated separately for each of the major functional activities. Analysis and control are simplified if excessive costs or inefficiencies can be traced to a functional activity or area of the facility.

The number of cost centers increases as the size and complexity of operations increase. More cost centers, however, require the collection of more data and, therefore, increase costs. For most facilities, four cost centers appear to collect adequate data without incurring excessive collection costs.

Three of the four cost centers (Receiving and Storage, Volume Reduction, and Effluent Handling and Treatment) are termed the direct cost centers because they can be directly associated with certain incinerator operations and unit processes. The operations included in each follow the process flow from input of raw wastes to output of effluents (Diagram I). The fourth, the Repairs and Maintenance cost center, cannot be directly associated with waste processing. Therefore, it is separated from other operations and not shown in the diagram. Because it incurs a large percentage of operating costs, a separate analysis is needed.

Although fewer cost centers would never be required, larger operations may require more cost centers. For instance, the Effluent Handling and Treatment cost center could be divided into Air Pollution, Water Treatment, and Residue Handling cost centers. Similarly, salvage or heat utilization operations should be put in separate cost centers.

These cost centers classify the operations by function. The costs incurred are for labor, parts and supplies, utilities, and overhead, and they must be allocated to the cost centers in an accurate and representative manner (Diagram II). Note that costs are first allocated to all four cost centers; the Repairs and Maintenance cost center is then allocated to the three direct cost centers. The result is the total operating cost for each direct cost center.

There are many alternatives for actually allocating the operating costs. A straight-forward method for each type of expense will be outlined. Labor costs may be allocated to the four cost centers based on the relative number of hours employees worked in each area and their respective wage rates. Utilities may be allocated based on an engineering estimate of the relative usage rates of the equipment in each cost center. Both water and electricity should be allocated. Parts and supplies will be allocated to each direct cost center

DIAGRAM I

INCINERATOR COST CENTERS

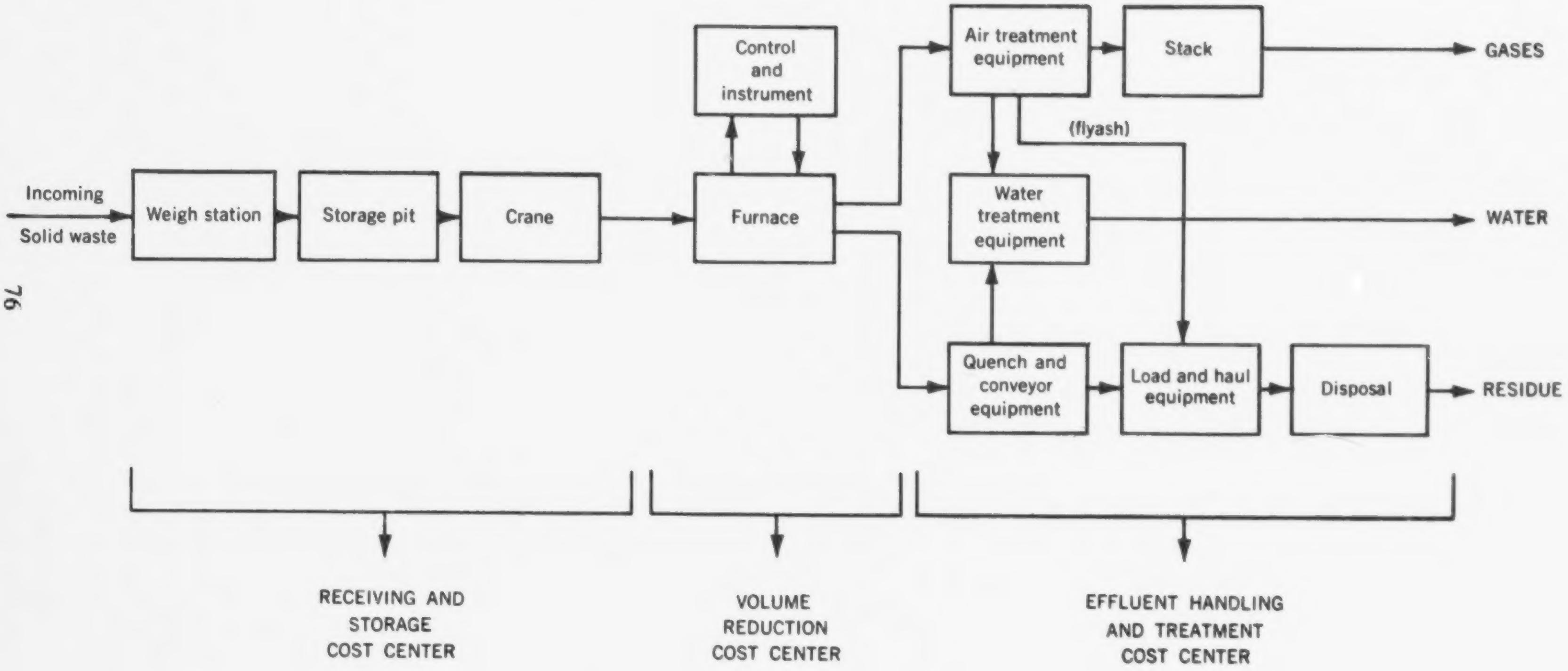
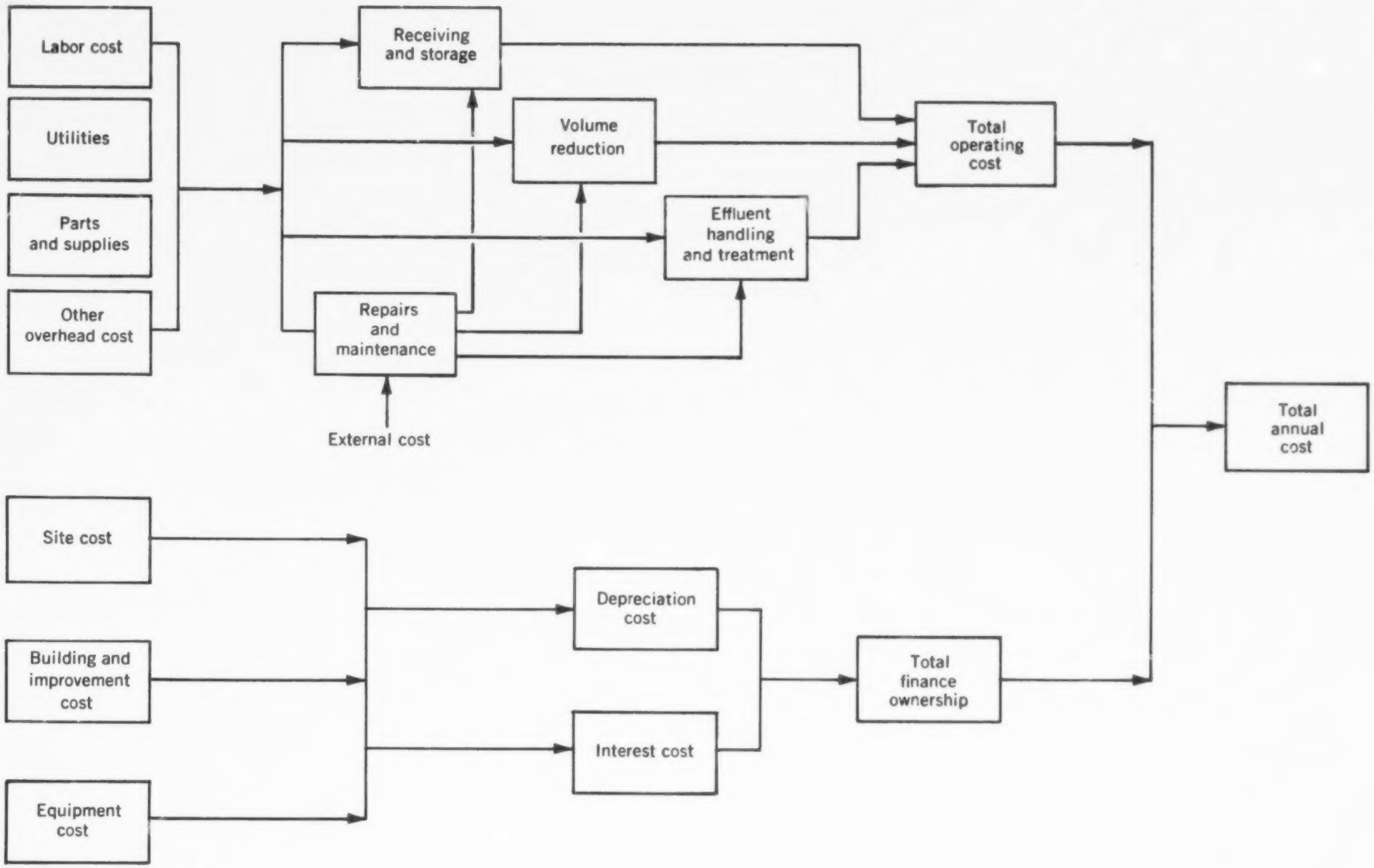


DIAGRAM II
ALLOCATION OF COSTS



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after first being recorded in the Repairs and Maintenance cost center. General overhead, which includes supervision, insurance, etc., can be allocated equally to each cost center or on the basis of the relative number of employees in each cost center. The latter technique is recommended. Finally, the Repairs and Maintenance cost center is allocated to the three direct cost centers based on the actual expenses incurred in each one.

The sum of the costs of these three direct cost centers is the total operating cost. The total annual cost of operations represents these operating costs plus the costs of financing and ownership.

The actual forms are designed to facilitate the collection and later allocation of costs to these cost centers.

Forms and Reports

The reports are most easily grouped into those that are used to collect the data on operations and those used to reduce and present the data for the purposes of analysis, decision making, and control.

This data reduction and presentation cannot be accomplished without the daily recording of all pertinent activity and cost information. Data not recorded daily are not retrievable at some later date. Incinerator personnel, supervisors, and others involved in operations primarily use the following forms (1 through 4) to record the data required.

Weekly Labor Report (Form 1). Daily entries of labor activity are recorded in duplicate at the site. One copy is forwarded to the payroll department for determining weekly wages. The incinerator supervisor and the accounting department use the other copy for computing total labor hours and assigning these hours and associated costs to the four cost centers.

Daily Truck Record (Form 2). The waste received and residue removed, as well as the types and sources of waste received, are recorded manually on this form for the entire day. (If the incinerator has a scale that automatically records the weight information, that part of the form would be replaced by the weight ticket or record of the scale.) Each delivery is recorded separately by the weighmaster. A

ORM 1

WEEKLY LABOR REPORT

INCINERATOR: ____________________

SIGNATURE: ____________________

DATE: ____/____/____

SHIFT: ____________________

Employee ident.	Day 1		Day 2		Day 3		Day 4		Day 5		Day 6		Day 7		Individual totals	Comments (Note causes and hours of absence, etc.)
	Cost center	Hours	Cost center	Hours	Cost center	Hours	Cost center	Hours	Cost center	Hours	Cost center	Hours	Cost center	Hours		
Tot	X		X		X		X		X		X		X			XXXXXXXXXXXXXX

Instructions: Incinerator supervisor to complete this form daily. List all employees separately including temporary help. "Hours" refers to hours worked daily. At the end of each week forward one copy to the payroll department and retain the original for further use.

Abbreviations of cost centers and workers to be assigned to each: R&S = receiving and storage: crane operator, weightmaster, tipping floor, and charging attendants. VR = volume reduction: stokers, control monitors, etc. EHT = effluent handling: residue haulers, disposal site operators, etc. R& M = repairs and maintenance: include all general maintenance workers and part time repairmen.

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FORM 2

DAILY TRUCK RECORD

INCINERATOR: ______________________ DATE: ______________________

SIGNATURE: ______________________ SHIFT: ______________________

No.	Truck * identification	Time	Wastes		Weight in	Weight out (or tare weight)	Net amount	
			Source	Type ‡			Wastes	Residue
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
12								
15								
16								
17								
18								
19								
20								
Totals		X	X	X	X	X		

Instruction: To be completed by weighmaster for each delivery of waste or removal of residue.

* Truck identification is number of the public truck; if private vehicle, the name of company for billing purposes.

† Source: R — residential; C — commerical; I — industrial.

‡ Type: R — rubbish; G — garbage (also unusual items).

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second weighing of the empty truck may be taken or the vehicle's tare weight (as officially determined by a licensing agency, etc.) may be substituted. The form is forwarded to the accounting department at the end of each month. In addition to utilizing recorded weight data to bill private users later, the sources and types of waste data are useful in special analyses of trends, compositions, and distributions of solid wastes in the community.

Daily Report on Incinerator Operations (Form 3). When there is actual downtime and repairs are required, the expenses that will be allocated to the three direct cost centers are recorded on the lower half of the two-purpose report. These data are particularly useful in analyzing equipment performance and cost. In addition, data on utility usage are recorded on the form at the end of each month.

The top of the report is used to summarize the daily operations. The employee and activity data give management personnel who are not at the site daily, but who still require daily feedback on operations, a quick and accurate summary of the day's activities. The performance data are also useful in assessing daily efficiency. The report is completed daily, sent to the main office, and filed for later use.

Incinerator Capital Investment Report (Form 4). This form is completed when construction is finished or when the cost system is first implemented. Only when improvements or new equipment are either constructed or purchased is it updated. In addition to collecting the data required to calculate depreciation for the period and allocating it to cost centers, the form also summarizes the bond and interest information required to compute the total costs of financing and ownership.

For the most part, Forms 1 through 4 are utilized to collect the data associated with the construction and operation of an incinerator. The cost of accumulating these data can only be justified by its intensive and effective utilization. This is accomplished by meaningful data reduction and presentation. The data must be presented clearly and quickly to the personnel who can use it most effectively for analyses and

FORM 3

DAILY REPORT ON INCINERATOR OPERATIONS

SITE: ______________________________ DATE: ________________

PERFORMANCE DATA
% Weight reduction $\left(\frac{\text{residue}}{\text{wastes burned}}\right)$:
Man hours per ton:
Tons of residue per trip:
Number of injuries:

EMPLOYEE HOURS				
Cost center	Shift			
	1	2	3	4
Receiving				
Volume reduction				
Effluent				
Repairs				
Totals				

ACTIVITY DATA		
	Loads	Tons
Wastes received		
Wastes burned		
Left in pit		
Residue		

REPAIRS AND MAINTENANCE DATA

Equipment description	Cost center	Cause	Hours down	Labor hours	Labor cost	Parts cost	External costs	Tot cos

UTILITY DATA
(Only complete this section at the end of the month)

	Electric	Gas	Water
Meter reading			

FORM 4

INCINERATOR CAPITAL INVESTMENT REPORT

INCINERATOR: ______________________________ DATE: ________________

Description	Size, capacity, amount, etc.	Date put in use	Estimated total life	New cost	Other comments	Yearly depreciation	Monthly depreciatio
Site:							
Land						X	X
Surveys							
Preparation							
Roads							
Other							
Buildings:							
Scale house							
Pit							
Offices							
Main building							
Stacks							
Other							
Equipment:							
Scales							
Crane(s)							
Furnace(s)							
Air pollution							
Water treatment							
Residue removal (including vehicles)							
Instrumentation and control							
Other							
Totals	X	X	X		X		

FINANCING DATA

Bond type	Face value	Premium or discount	Interest rate	Yearly interest *	Monthly interest

Instructions: To be completed by supervisor or accounting department. Depreciation may be straight-line or on an accelerated basis.

* Interest must account for net effect of premium or discount on bond sale.

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control. The following forms (as well as Form 3) are designed to fulfill these objectives.

Incinerator Operations Summary (Form 5). This form summarizes six distinct groups of information about incinerator operations for a specific period. For control purposes, monthly reports would be desirable, although less frequent preparation would be possible. The first two segments present activity and operating cost data for the total operation. Costs are broken down by type to aid the cost analysis, and the activity and performance factors are designed to help analyze inefficiencies and performance. The remaining four sections break the costs into the four cost centers. Total operating costs are presented for each area as are other factors that may be useful to analyze the functional activities. Obviously, there are many other factors and costs that could be presented. The ones illustrated, however, are adequate for most analyses. Nonetheless, modifications or additions should be made for facilities with different operations and data requirements.

This form, designed for control purposes, contains only controllable expenses for which the supervisor can be held accountable; capital or financing costs are not included. The form is prepared by the accounting department from the data in Forms 1, 2, and 3 and additional data on file concerning labor rates, insurance, fringe benefits and charges from other departments, external expense billings, etc. Copies of the form are forwarded to both the facility supervisor and to his superior. Analysis of the form indicates excessive expenses and aids the supervisor in taking corrective action.

Incinerator Total Cost Report (Form 6). All the activities and costs incurred by the incinerator during the period are summarized from data in present and past Incinerator Operations Summaries (Form 5) and from the depreciation and interest data available in the Incinerator Capital Investment Report (Form 4). Semiannual and annual preparation would be sufficient. Form 6 — Alternate can be used if disposal charges or other types of revenues are associated with incinerator operations.

FORM 5

INCINERATOR OPERATIONS SUMMARY

INCINERATOR:

REPORT PERIOD: from to

ACTIVITY AND PERFORMANCE

	Actual amount	± % Budget variance
Tons incinerated		
% Weight reduction		
Total labor hours		
% Capacity utilized		
% Capacity available		
% Utilized/% available		

OPERATING COST TOTALS

	Actual amount	± % Budget variance
Total operating cost		
Total labor cost		
Utilities cost		
Parts and supplies		
Outside charges		
Overhead		

RECEIVING COSTS

	Actual amount	± % Budget variance
Total operating cost per ton		
Labor hours		

VOLUME REDUCTION COSTS

	Actual amount	± % Budget variance
Total operating cost per ton		
Labor hours		
Average operating temperature		

EFFLUENT HANDLING COSTS

	Actual amount	± % Budget variance
Total operating cost per ton		
Gallons of water per ton		
Tons of residue per load		

REPAIRS AND MAINTENACE COSTS

	Actual amounts	± % Budget variance
Total operating cost		
Receiving repair costs		
Volume reduction repair costs		
Effluent handling repair costs		

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FORM 6

INCINERATOR TOTAL COST REPORT

SITE: ______________________ REPORT PERIOD: from ____________ to ____________

Data	For this period	± % Variance from budget for this period	Year to date	± % Variance from budget for year to date
Tons incinerated				
Weight reduction				
Total operating cost				
Total financing and ownership cost				
Total cost				
Operating cost per ton				
Financing and ownership, cost per ton				
Total cost per ton				

Instructions: To be completed by accounting department from data available in "Incinerator Operations Summary" and "Incinerator Capital Investment Report" when requested or periodically. Copy sent to city manager, head of department of public works, or their equivalent.

FORM 6 — Alternate

INCINERATOR TOTAL COST SUMMARY

SITE: ______________________ REPORT PERIOD: from ____________ to ____________

Data	For this period	Budget—this period	Year to date	Budget—year to date
Tons of waste incinerated				
Percent weight reduction				
Total operating cost				
Total financing and ownership cost				
Total cost				
Operating cost per ton				
Financing and ownership cost per ton				
Total cost per ton				
Revenues—other communities				
Revenues—private collectors				
Revenues—miscellaneous				
Total revenues				
Total revenues per ton				
Net cost (profit)				
Net cost (profit) per ton				

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Summary of Information Flow

Operating data are accumulated daily at the incinerator site and transmitted periodically to the accounting department. The accounting department combines these reports with additional information it accumulates to get total operating costs. This summary is then returned to the supervisor for his own use. Next, the accounting department combines the operating cost data with the depreciation and interest cost data (from the Incinerator Capital Investment Reports) to compute total costs for the period. This total cost information is then given to the heads of departments of sanitation and public works, or their equivalents.

System Utilization

Only with efficient and intensive utilization of the information generated from the accounting system and forms can the additional time, effort, and money required to implement and maintained the system be justified. The system's intensive use promotes two major objectives: quality control and cost control. Reduced costs must be accomplished without deteriorating and operating quality. Similarly, quality is interrelated with the costs of obtaining it.

All the factors that affect the quality and effectiveness of incinerator operations can be translated into costs. Amount of volume reduction, residue characteristics, and the levels of stack emissions and water pollution determine the quality of operations. Cost control does not call for economizing at the expense of quality. On the contrary, once a level of acceptable operation has been determined along with the attendant costs, the cost control system can help the supervisor maintain that level of operation.

Effective cost control requires timely recognition of excessive costs and identification of responsibility for the increased costs. Comparing units costs (cost per ton of waste incinerated) with both the current budget and the corresponding period last year helps indicate excessive costs. The use of unit cost facilitates the analysis of costs, independent of changes in the level of activity. The cost-center breakdowns help single out the responsible factor or person. This system allows both of these critical factors to be determined, corrective action may then be effectively initiated.

The Incinerator Total Cost Report (Form 6) can indicate to the highest level of municipal management, i.e., the city manager or the head of the sanitation department, if costs are excessive. If so, the supervisor of the particular facility can be held responsible to the extent that his operating costs have increased. The supervisor, in turn, can analyze the cause of this cost rise. He may trace the increased cost to the type of cost, as well as the cost center, and possibly to the employee or piece of equipment responsible. All of the needed data are in Form 5 (the Incinerator Operations Summary).

Control of Air Pollution Originating From Federal Installations

Announcement of Signing of Executive Order 11282.
May 26, 1966

President Johnson today signed an Executive order requiring all Federal agencies to take steps to prevent and control air pollution from Federal installations.

The order directs the heads of all Federal agencies to lead in the administration's efforts to improve the quality of the Nation's air. Today's order is similar to one the President issued last November directing the Federal Government to provide effective leadership in the battle against water pollution.

The air pollution Executive order is the result of extensive consultation with Federal agencies and with industries affected by the order. The Department of Health, Education, and Welfare is issuing standards to supplement the order, by setting precise limitations on emissions which will be allowed from Federal buildings and facilities.

Today's order requires that plans for new Federal facilities and buildings in the United States include provisions for air pollution control measures necessary to comply with the standards issued by the Department of Health, Education, and Welfare. In addition, the order directs the head of each agency to examine existing installations and to present to the Bureau of the Budget, by July 1, 1967, an orderly schedule for bringing all such installations up to the required standards.

In signing the order, the President stated that the most difficult problem encountered in writing the order was the lack of an economically feasible technology for controlling emissions of sulfur. The Federal Government has proposed spending more than $3 million in 1967 on research to control sulfur emissions. This includes $1 million for designing four sulfur-removal pilot plants, the construction of which plants would cost a total of $8 million. The President has directed the Secretaries of the Interior and Health, Education, and Welfare to explore with the Bureau of the Budget the feasibility of increasing the Federal effort to find a solution to the sulfur emission problem.

The President said that a major part of the responsibility for sulfur research rests with the utilities, the coal and oil industries, and other groups which will feel the economic efforts of more stringent air pollution regulations. He pointed out that these industries had increased their expenditures for air pollution research in the past few years, but stated that much greater efforts are needed.

The President emphasized that, although there were great technological and economic problems in the abatement of air pollution, the battle for cleaner air remained a major objective of his administration, and an essential element in a better environment for America.

NOTE: For the text of Executive Order 11282, see the following item.

Control of Air Pollution Originating From Federal Installations

Executive Order 11282. May 26, 1966

Prevention, Control, and Abatement of Air Pollution by Federal Activities

By virtue of the authority vested in me as President of the United States and in furtherance of the purpose and policy of the Clean Air Act, as amended (42 U.S.C. 1857), it is ordered as follows:

Section 1. *Policy.* The heads of the departments, agencies, and establishments of the Executive Branch of the Government shall provide leadership in the nationwide effort to improve the quality of our air through the prevention, control, and abatement of air pollution from Federal Government activities in the United States. In order to achieve these objectives—

(1) Emissions to the atmosphere from Federal facilities and buildings shall not be permitted if such emissions endanger health or welfare, and emissions which are likely to be injurious or hazardous to people, animals, vegetation, or property shall be minimized. The procedures established in section 3 of this Order shall be followed in minimizing pollution from existing facilities and buildings.

(2) New Federal facilities and buildings shall be constructed so as to meet the objectives prescribed by this Order and the standards established pursuant to section 5 of this Order.

(3) The Secretary of Health, Education, and Welfare shall, in administering the Clean Air Act, as amended, provide technical advice and assistance to the heads of other departments, agencies, and establishments in connection with their duties and responsibilities under this Order. The head of each department, agency, and establishment shall establish appropriate procedures for securing advice from, and consulting with, the Secretary of Health, Education, and Welfare.

(4) The head of each department, agency, and establishment shall ensure compliance with section 107(a) of the Clean Air Act, as amended (42 U.S.C. 1857f(a)), which declares it to be the intent of Congress that Federal departments and agencies shall, to the extent practicable and consistent with the interests of the United States and within available appropriations, cooperate with the Department of Health, Education, and Welfare and with any air pollution control agency in preventing and controlling pollution of the air.

Sec. 2. *Procedures for new Federal facilities and buildings.* A request for funds to defray the cost of designing and constructing new facilities and buildings in the United States shall be included in the annual budget estimates of a department, agency, or establishment only if such request includes funds to defray the costs of such measures as may be necessary to assure that the new facility or building will meet the objectives prescribed by this Order and the standards established pursuant to section 5 of this Order. Air pollution control needs shall be considered in the initial stages of planning for each new installation.

Sec. 3. *Procedures for existing Federal facilities and buildings.* (a) In order to facilitate budgeting for corrective and preventive measures, the head of each department, agency, and establishment shall provide for an examination of all existing facilities and buildings under his jurisdiction in the United States and shall develop and present to the Director of the Bureau of the Budget, by July 1, 1967, a phased and orderly plan for installing such improvements as may be needed to prevent air pollution, or abate such air pollution as may exist, with respect to such buildings and facilities. Subsequent revisions needed to keep any such plan up to date shall be submitted to the Director of the Bureau of the Budget with the annual report required by paragraph (b) of this section. Future construction work at each such facility and the expected future use of the facility shall be considered in developing such a plan. Each such plan, and any revision therein, shall be developed in consultation with the Secretary of Health, Education, and Welfare in order to ensure that adoption of the measures proposed thereby will result in the prevention or abatement of air pollution in conformity with the objectives prescribed by this Order and the standards prescribed pursuant to section 5 of this Order.

(b) The head of each department, agency, and establishment who has existing facilities and buildings under his jurisdiction in the United States shall present to the Director of the Bureau of the Budget, by July 1, 1968, and by the first of each fiscal year thereafter, an annual report describing progress of his department, agency, or establishment in accomplishing the objectives of its air pollution abatement plan.

Sec. 4. *Objectives for Federal facilities and buildings.* (a) Except for discharges of radioactive emissions which are regulated by the Atomic Energy Commission, Federal facilities and buildings shall conform to the air pollution standards prescribed by the State or community in which they are located. If State or local standards are not prescribed for a particular location, or if the State or local standards are less stringent than the standards established pursuant to this Order, the standards prescribed pursuant to section 5 of this Order shall be followed.

(b) The emission of flyash and other particulate matter shall be kept to a minimum.

(c) Emission of sulfur oxides shall be minimized to the extent practicable.

(d) Wherever appropriate, tall chimneys shall be installed in order to reduce the adverse effects of pollution. The determination of chimney height shall be based on air quality criteria, land use, and meteorological, topographical, aesthetic, and operating factors.

(e) Solid fuels and ash shall be stored and handled so as not to release to the atmosphere dust in significant quantities. Gasoline or any volatile petroleum distillate or organic liquid shall be stored and handled so as not to release to the atmosphere vapor emissions in significant quantities.

(f) In urban areas refuse shall not be burned in open fires and in rural areas it shall be disposed of in such a manner as to reasonably minimize pollution. Refuse shall not be left in dumps without being covered with inert matter within a reasonably short time. Whenever incinerators are used they shall be of such design as will minimize emission of pollutant dusts, fumes, or gases.

(g) Pollutant dusts, fumes, or gases (other than those for which provision is made above) shall not be discharged to the atmosphere in quantities which will endanger health or welfare.

(h) The head of each department, agency, and establishment shall, with respect to each installation in the United States under his jurisdiction, take, or cause to be taken, such action as may be necessary to ensure that discharges of radioactive emissions to the atmosphere are in accord with the rules, regulations, or requirements of the Atomic Energy Commission and the policies and guidance of the Federal Radiation Council as published in the Federal Register.

(i) In extraordinary cases where it may be required in the public interest, the Secretary of Health, Education, and Welfare may exempt any Federal facility or building from the objectives of paragraphs (a) through (g) of this section.

Sec. 5. *Standards.* (a) The Secretary of Health, Education, and Welfare shall prescribe standards to implement the objectives prescribed by paragraphs (a) through (g) of section 4 of this Order. Such standards may modify these objectives whenever the Secretary of Health, Education, and Welfare shall determine that such modifications are necessary in the public interest and will not significantly conflict with the intent of this Order. Prior to issuing any changes in such standards, the Secretary of Health, Education, and Welfare shall consult with appropriate Federal agencies and shall publish the proposed changes in the Federal Register thirty days prior to their issuance. All such standards prescribed by the Secretary shall be published in the Federal Register.

(b) The permits authorized by section 107(b) of the Clean Air Act, as amended (42 U.S.C. 1857f(b)), may be used to carry out the purposes of this Order as the Secretary of Health, Education, and Welfare may deem appropriate.

Sec. 6. *Prior Executive Order superseded.* Executive Order No. 10779 of August 20, 1958, is hereby superseded.

Lyndon B. Johnson

The White House
May 26, 1966

[Filed with the Office of the Federal Register, 8:49 a.m., May 27, 1966]

Title 42—PUBLIC HEALTH

Chapter I—Public Health Service, Department of Health, Education, and Welfare

SUBCHAPTER F—QUARANTINE, INSPECTION, AND LICENSING

PART 76—PREVENTION, CONTROL, AND ABATEMENT OF AIR POLLUTION FROM FEDERAL GOVERNMENT ACTIVITIES: PERFORMANCE STANDARDS AND TECHNIQUES OF MEASUREMENT

Pursuant to section 5 of Executive Order No. 11282, the Secretary of Health, Education, and Welfare hereby amends Subchapter F of Title 42, Code of Federal Regulations, by adding a new Part 76, as follows:

Sec.

76.1 Definitions.
76.2 Intent.
76.3 Applicability.
76.4 Combustion of fuel.
76.5 Sulfur oxides.
76.6 Stacks.
76.7 Storage and handling of fuels and ash.
76.8 Disposal of refuse.
76.9 Other pollution producing processes.

Authority: The provisions of this Part 76 issued under section 5 of Executive Order 11282.

§ 76.1 Definitions.

As used in this part:

(a) "Executive Order" means Executive Order No. 11282.

(b) "Nonurban areas" means all areas other than urban areas.

(c) "Ringelmann Scale" means the Ringelmann Scale as published in the U.S. Bureau of Mines Information Circular 7715.

(d) "Secretary" means the Secretary of Health, Education, and Welfare.

(e) "Smoke Inspection Guide" means the U.S. Public Health Service Smoke Inspection Guide described in Part 75 of this title.

(f) "Urban areas" means those areas classified as urban in the latest available Federal census, or as Standard Metropolitan Statistical Areas by the Bureau of the Budget.

§ 76.2 Intent.

It is the intent of these standards that emissions to the atmosphere from Federal facilities and buildings shall not be permitted if such emissions endanger health or welfare and that emissions which are likely to be injurious or hazardous to people, animals, vegetation, or property shall be minimized.

§ 76.3 Applicability.

(a) Unless otherwise indicated, the standards in this part apply to both new and existing Federal facilities and buildings. These standards are effective upon publication in the *Federal Register*, except for those facilities and buildings which are likely to require installation of improvements under the plan to be submitted in accordance with section 3 of the Executive Order.

(b) Except for discharges of radioactive effluents which are regulated by the Atomic Energy Commission, Federal facilities and buildings shall conform to the air pollution standards prescribed by the State or community in which they are located. If State or local standards are not prescribed for a particular location, or if the State or local standards are less stringent than the standards prescribed herein, the standards in this part shall be applicable to discharges from such Federal facilities and buildings except as otherwise indicated.

(c) Temporary operations that may result in potential air pollution problems, such as those associated with research, development, test, evaluation, space, and military activities, shall be conducted with such precautions and safeguards as are needed to achieve the intent of these standards.

(d) The Secretary may, upon application of the relevant department, agency or establishment, exempt any Federal facility or building from the objectives contained in section 4 of the Executive order and from any or all of these standards whenever he determines that the activities of such building or facility will not significantly conflict with the intent of the Executive order and that such an exemption is in the public interest.

§ 76.4 Combustion of fuel.

(a) The following standards apply to the combustion units of facilities and buildings having a heat input of less than 1,000 million B.t.u./hour, other than fireplaces, stoves, or grills burning wood or charcoal:

(1) Manually fired equipment shall not be installed as new or replacement equipment, except for the burning of anthracite, coke, or smokeless fuel.

(2) (i) For new units, except during startup, cleaning of fires, or soot blowing, the density of any emission to the atmosphere shall not exceed No. 1 on the Ringelmann Scale or the Smoke Inspection Guide.

(ii) For existing units, except during startup, cleaning of fires, or soot blowing, the density of any emission to the atmosphere shall not exceed No. 2 on the Ringelmann Scale or the Smoke Inspection Guide.

(3) A photoelectric or other type smoke detector, recorder, or alarm shall be installed on units larger than ten million BTU per hour input, except where gas or light oil (No. 2 or lighter), is burned.

(4) During routine operation, the emission of particles larger than 60 microns shall not normally occur.

(5) Means shall be provided in all newly constructed units and wherever practicable in existing units to allow the periodic measurement of flyash and other particulate matter.

(6) All new or replacement spreader stoker installations shall be of a type that automatically discharges ashes to the ash pit either continuously or in very frequent small increments, and flyash shall be reinjected only from boiler passes.

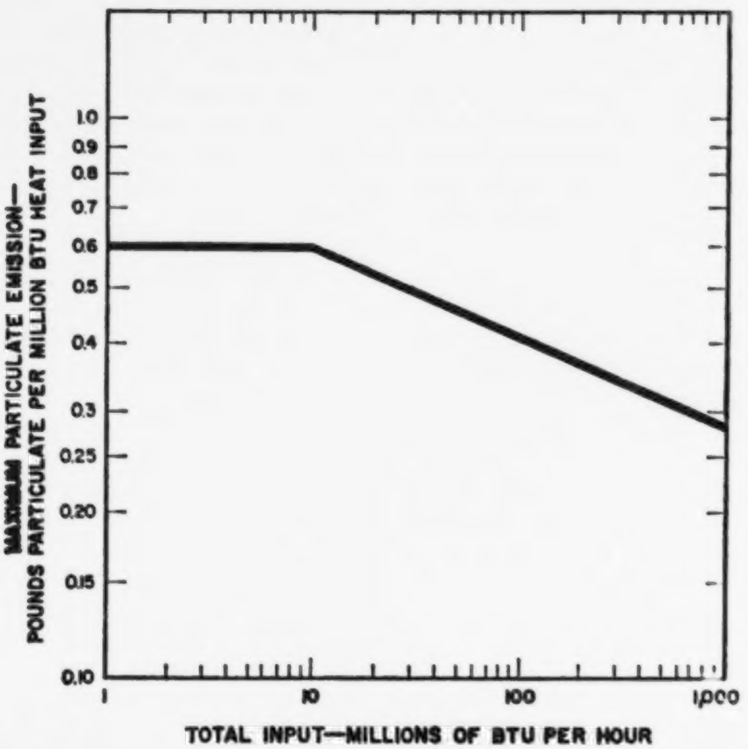
(7) For units of less than 10 million BTU/hour heat input, the emission of flyash and other particulate matter shall not exceed 0.6 pounds of particulate matter per million BTU heat input, as measured by the American Society of Mechanical Engineers Power Test Code No. 27 for "Determining Dust Concentrations in a Gas Stream," or equivalent test method.

(8) For units between 10 million and 1,000 million BTU/hour heat input, the emission of flyash and other particulate matter shall not exceed that specified in figure 1, as measured by the test method specified in subparagraph (7) of this paragraph. Existing units shall meet this standard within the time designated by the plan submitted in accordance with section 3 of the Executive order except that with respect to existing spreader stoker units the plan may specify certain units which may emit particulate matter at an interim rate not exceeding 0.6 lbs/million BTU heat input.

(b) For units having a heat input of more than 1,000 BTU/hour, the appropriate department, agency, or establishment shall seek special advice from the Secretary with regard to smoke, flyash, and other particulate emissions.

FIGURE I

MAXIMUM EMISSION OF PARTICULATE MATTER
FROM FUEL BURNING INSTALLATIONS



§ 76.5 **Sulfur oxides.**

(a) Combustion units of facilities or buildings not located in areas specified by the Secretary under paragraph (c) of this section and whose heat input is less than 1,000 million BTU/hour shall burn the lowest sulfur content fuel that is reasonably available. In determining reasonable availability, the factors to be considered include, among others, price, firmness of supply, extent of existing pollution, and assurance of supply under adverse weather and natural disaster conditions.

(b) For combustion units of Federal facilities or buildings not located in areas specified by the Secretary under paragraph (c) of this section and whose heat input is more than 1,000 million BTU/hour, the appropriate department, agency, or establishment shall seek special advice from the Secretary with regard to sulfur-oxide emissions.

(c) (1) For Standard Metropolitan Statistical Areas or Standard Consolidated Areas whose central city has a population greater than 2 million and a population density greater than 15,000 persons per square mile, the Secretary will, within 6 months after the effective date of the regulations in this part, establish by regulation limits on the emission of sulfur oxides to the atmosphere or prescribe such control steps or measures as may be necessary over time to abate or control sulfurous pollution from

Federal installations. The limits or measures so established shall be no less stringent than the relevant State or local requirements.

(2) Such limits or measures shall be established only after consultation with appropriate Federal, State and local officials and affected parties. Not less than 30 days prior to prescribing such limits or measures, the Secretary will publish in the *Federal Register* notice of his intention to adopt such limits or measures, and will thereafter publish in the *Federal Register* the limits or measures established. The Secretary may at any time designate other urban areas which suffer from extremely high air pollution levels, and after similar consultation, and publication in the *Federal Register*, prescribe such limits or measures as he determines are necessary to carry out the intent of this order.

(d) The emission of the oxides of sulfur the atmosphere shall be monitored at regular intervals by determining the sulfur content of the fuel used or by determining the sulfur content of flue gases.

§ 76.6 Stacks.

For buildings or facilities in nonurbanized areas, the particle emission standards of § 76.4(a) (7) and (8) may be revised for an individual installation by an amount to be determined by the Secretary, when:

(a) The stack height exceeds by 2½ times the height of the highest building in that area, and

(b) The pollution level in any area will not be significantly increased thereby.

For large plants the determination of chimney height shall be based on air quality criteria, land use, and meteorological, topographical, aesthetic, and operating factors.

§ 76.7 Storage and handling of fuels and ash.

(a) Solid fuels and ash shall be stored and handled so as not to release to the atmosphere dust in significant quantities.

(b) In quantities of 40,000 gallons or more, gasoline or any volatile petroleum distillate or organic liquid having a vapor pressure of 1.5 p.s.i.a. or greater under actual storage conditions shall be stored in pressure tanks or reservoirs or shall be stored in containers equipped with a floating roof or vapor recovery system or other vapor emission control device.

(c) Stationary gasoline storage tanks with a capacity of 250 gallons or more shall be equipped with either submerged filling inlets or with vapor recovery or emission control systems such that loss of vapor to the atmosphere during filling operations shall be minimized.

(d) Gasoline or petroleum distillate tank car or tank truck loading facilities handling 20,000 gallons per day or more shall be equipped with submersible filling arms or other vapor emission control systems.

§ 76.8 Disposal of refuse.

(a) Refuse shall not be burned in open fires in urban areas. In nonurban areas there shall not be burned in open fires, within a 24-hour period, more than 25 pounds of material at a single site nor more than 500 pounds of material at any number of sites within a 1-mile radius, except that these quantities may be exceeded when the open burning occurs at diverse sites such as are associated with railroad rights-of-way, interurban highways, irrigation canals, forests, agricultural operations, etc. Deteriorated or unused explosives, munitions, and certain hazardous materials may be burned in open fires, in accordance with recognized procedures. Refuse shall not be left in dumps without being covered with inert matter within a reasonably short time.

(b) Refuse shall be incinerated only in facilities specially designed for that purpose. Incinerators shall meet the emission visibility standards of § 76.4 (a) (2) and (a) (3). In addition, for installations burning 200 pounds of refuse or more per hour, emissions shall not exceed 0.2 grain of particulate matter per standard cubic foot of dry flue gas corrected to 12 percent carbon dioxide (without the contribution of auxiliary fuel), and shall not normally include particles larger than 60 microns. For installations burning fewer than 200 pounds of refuse per hour, emissions shall not exceed 0.3 grain of particulate matter per standard cubic foot of dry flue gas corrected to 12 percent carbon dioxide (without the contribution of auxiliary fuel).

§ 76.9 Other pollution producing processes.

For dusts, fumes, or gases from any process not heretofore described, except for discharges of radioactive effluents regulated by the Atomic Energy Commission, whatever measures may be necessary to comply with the intent of these regulations shall be applied. This will generally require the installation of equipment or devices to minimize such emissions to the point where they will meet the standards contained in these regulations. For processes which emit toxic substances in quantities which might endanger health or welfare and for fires which emit smoke or fumes at official firefighting schools, the appropriate department, agency, or establishment shall seek special advice from the Secretary.

(Note: The Department of Health, Education, and Welfare will, from time to time, and after consultation with industries concerned, issue "Guides of Good Practice" for specific operations to aid Federal departments, agencies, and establishments in the selection of equipment and methods for meeting the performance standards. For emissions not covered herein, or for which there have been issued no applicable "Guides of Good Practice," the Department of Health, Education, and Welfare will provide technical material and consultation to departments, agencies, and establishments requesting such assistance. Requests for "Guides of Good Practice," technical material, or consultation should be directed either to the Federal Facilities Section, Abatement Branch, Division of Air Pollution, Public Health Service, Department of Health, Education, and Welfare, Washington, D.C., 20201, or to the appropriate Regional Air Pollution Program Director of the Public Health Service located in the Department of Health, Education, and Welfare Regional Offices.)

Dated: June 2, 1966.

John W. Gardner,
Secretary of Health, Education,
and Welfare.

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